

# 1976

## Yearbook of **ASTRONOMY**

**Edited by Patrick Moore**



**1976 YEARBOOK OF ASTRONOMY Patrick Moore**

Sidgwick & Jackson  
W W Norton

# 1976 Yearbook of ASTRONOMY

*Edited by* Patrick Moore

The astronomical year to come is presented by the ever-popular Patrick Moore. He himself contributes notes and charts on the events of 1976 to which astronomers can look forward.

The 1976 *Yearbook* also contains articles on:

*Mariner 10 to Venus and Mercury*  
by H. G. Miles

*The BL Lacertae Objects*  
by D. A. Allen

*Titan—A Satellite with a Recycled  
Atmosphere* by G. E. Hunt

*Prominence Observations for the  
Amateur, using a Narrow Band  
Filter* by Ramon Lane

*Sense about Stellar Photography*  
by W. E. Pennell

*Black Holes* by David L. Block

*Easy Double Stars* by Patrick Moore

'This is the fifteenth *Yearbook*, and it follows the pattern of its predecessors, with one slight difference; for the first time we include one rather more technical article—David Block's contribution about Black Holes. We welcome both our former and our new writers in the article section; and, of course, Dr J. G. Porter has provided all the essential information for Part One.'—  
*Patrick Moore*

**1976**

**Yearbook of Astronomy**



# **1976 Yearbook of Astronomy**

*Edited by*

**PATRICK MOORE**

**Sidgwick & Jackson Limited**  
LONDON

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## **Editor's Foreword**

This is the fifteenth *Yearbook*, and it follows the pattern of its predecessors, with one slight difference; for the first time we include one rather more technical article – David Block's contribution about Black Holes. We welcome both our former and our new writers in the article section; and, of course, Dr J. G. Porter has provided all the essential information for Part 1.

My thanks are again due to our line-drawing artist, Lawrence Clarke.

PATRICK MOORE

*Selsey, 1975*



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WRIGHT, H. N. D. *The Surface of Saturn*: 1964.

## Preface

New readers will find that all the information in this *Yearbook* is given in diagrammatic or descriptive form; the positions of the planets may easily be found on the specially designed star charts, while the monthly notes describe the movements of the planets, and give details of other astronomical phenomena that may be observed from these latitudes. The reader who needs more detailed information will find *Norton's Star Atlas* (Gall and Inglis) an invaluable guide, while more precise positions of the planets and their satellites, together with predictions of occultations, meteor showers and periodic comets may be found in the *Handbook* of the British Astronomical Association. A somewhat similar publication is the *Observer's Handbook* of the Royal Astronomical Society of Canada, and readers will also find details of forthcoming events given in the American *Sky and Telescope*. This monthly publication also produces a special Occultation Supplement giving predictions for the United States and Canada.

### *Important Note*

The star charts are drawn, and the notes are, in general, designed for use in latitude 52 degrees north, but may be used without alteration throughout the British Isles, and (except in the case of eclipses and occultations) in other countries of similar north latitude.

The times given on the star charts and in the Monthly Notes are generally given as local times, using the 24-hour clock, the day beginning at midnight. Ignoring small differences of longitude, this local time may be taken as Greenwich Mean Time (G.M.T.) in the British Isles, or as the appropriate Standard Time in other

## PREFACE

**Time Zones.** If Summer Time is in use, the clocks will have been advanced by one hour, and this hour must be subtracted from the clock time to give G.M.T.

In Great Britain and N. Ireland, Summer Time will be in force in 1976 from 21 March 02<sup>h</sup> to 24 October 02<sup>h</sup> G.M.T.

The times of a few events (e.g., eclipses) are given in G.M.T., and this may be converted to Local Mean Time by subtracting the west longitude (or adding the east longitude).

Local Mean Time = G.M.T. - West Longitude

Similarly,

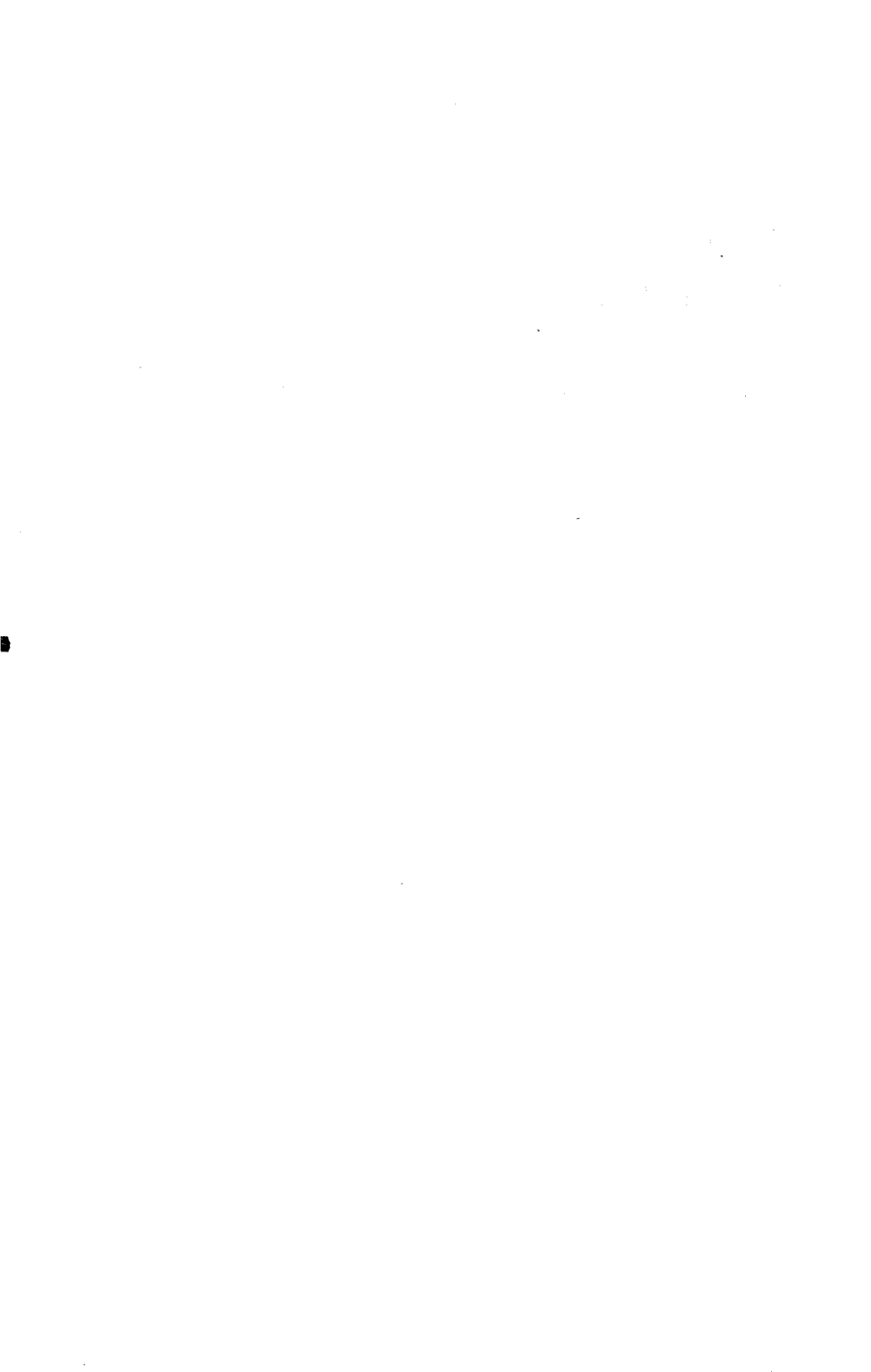
Eastern Standard Time = G.M.T. - 5 hours,

Central Standard Time = G.M.T. - 6 hours, etc.

**PART ONE**

**Events of 1976**

**Monthly Charts and Astronomical Phenomena**



## Notes on the Star Charts

The stars, together with the Sun, Moon and planets, seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume on pages 20 to 45 have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitudes of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the bright stars.

There are four such charts at each opening, and these give a complete coverage of the sky up to an altitude of  $62\frac{1}{2}$  degrees; there are twelve such sets to cover the entire year. The upper two charts show the southern sky, south being at the centre; the coverage is 200 degrees in azimuth, from a little north of east

# 1976 YEARBOOK OF ASTRONOMY

(top left) to a little north of west (top right). The two lower charts show the northern sky, from a little south of west (lower left) to a little south of east (lower right). There is thus an overlap east and west.

The charts have been drawn for a latitude of 52 degrees, but may be taken without appreciable error to apply to all parts of the British Isles. They will also be equally suitable for any other part of the world having a north latitude of about 52 degrees – e.g. parts of Europe and Asia, and Canada. In such cases the times given must be taken as local time, and not G.M.T., which applies only to the British Isles.

Because the sidereal day is shorter than the solar day, the stars appear to rise and set about four minutes earlier each day, which amounts to two hours in a month. Hence, the twelve sets of charts are sufficient to give the appearance of the sky throughout the day at intervals of two hours, or at the same time of night at monthly intervals throughout the year. The actual range of dates and times when the stars on the charts are visible is indicated at the top of each page. This information is summarized in the following table, which gives the number of the star chart to be used for any given month and time.

| G.M.T.    | 16 <sup>h</sup> | 18 <sup>h</sup> | 20 <sup>h</sup> | 22 <sup>h</sup> | 0 <sup>h</sup> | 2 <sup>h</sup> | 4 <sup>h</sup> | 6 <sup>h</sup> |
|-----------|-----------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|----------------|
| January   | 10              | 11              | 12              | 1               | 2              | 3              | 4              | 5              |
| February  |                 | 12              | 1               | 2               | 3              | 4              | 5              | 6              |
| March     |                 |                 | 2               | 3               | 4              | 5              | 6              |                |
| April     |                 |                 | 3               | 4               | 5              | 6              |                |                |
| May       |                 |                 | 4               | 5               | 6              | 7              |                |                |
| June      |                 |                 | 5               | 6               | 7              |                |                |                |
| July      |                 |                 | 6               | 7               | 8              | 9              |                |                |
| August    |                 |                 | 7               | 8               | 9              | 10             | 11             |                |
| September |                 | 7               | 8               | 9               | 10             | 11             | 12             |                |
| October   |                 | 8               | 9               | 10              | 11             | 12             | 1              |                |
| November  | 8               | 9               | 10              | 11              | 12             | 1              | 2              | 3              |
| December  | 9               | 10              | 11              | 12              | 1              | 2              | 3              | 4              |

## NOTES ON THE STAR CHARTS

The charts are drawn to scale, and estimates of altitude and azimuth may be made from them. These values will necessarily be mere approximations, since no observer will be exactly on the meridian of Greenwich at 52 degrees latitude, but they will generally serve for the identification of stars and planets. The horizontal measurements, marked at every ten degrees, give the azimuths (or true bearings) measured from the north round through east (90 degrees), south (180 degrees), and west (270 degrees). The vertical measurements, similarly marked, give the altitudes of the stars up to  $62\frac{1}{2}$  degrees.

The ecliptic is drawn as a broken line on which the longitude is marked at every ten degrees; the positions of the planets at any time are then easily found by reference to the table on page 48.

There is a curious illusion that stars at an altitude of 60 degrees or more are actually overhead, and the beginner may often feel that he is leaning over backwards in trying to see them. These high-altitude stars, being nearer the pole, move more slowly across the sky, and a different kind of map may therefore be used. These overhead stars are given separately on pages 44 and 45, the entire year being covered at one opening. Each of the four maps shows the overhead stars at times which correspond to those of three of the main star charts. The position of the zenith in latitude 52 degrees is indicated by a cross, and this cross also marks the centre of a circle which is 35 degrees from the zenith, and which therefore indicates an altitude of 55 degrees; there is thus a small overlap with the main charts.

The broken line leading from north to south is numbered to indicate the corresponding main chart. Thus on page 44 the N-S line numbered 6 is to be regarded as an extension of the S line of chart 6 on pages 30 and 31, and at the top of these pages are given dates and times which are appropriate.

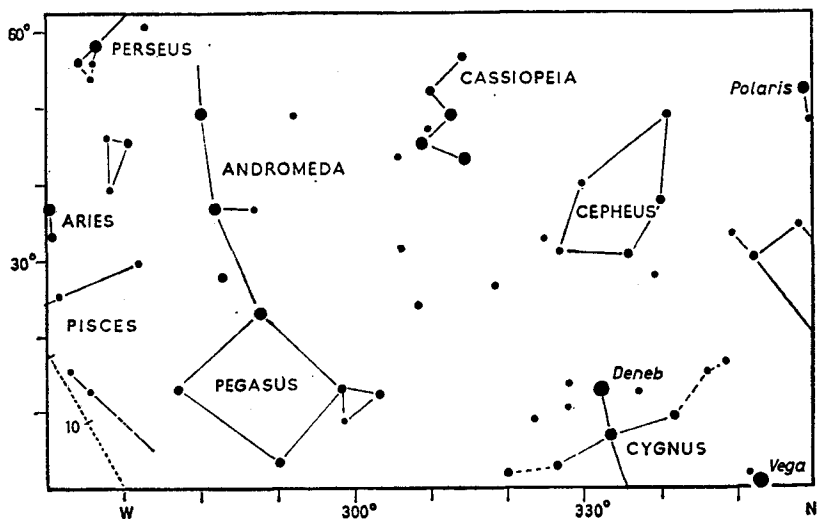
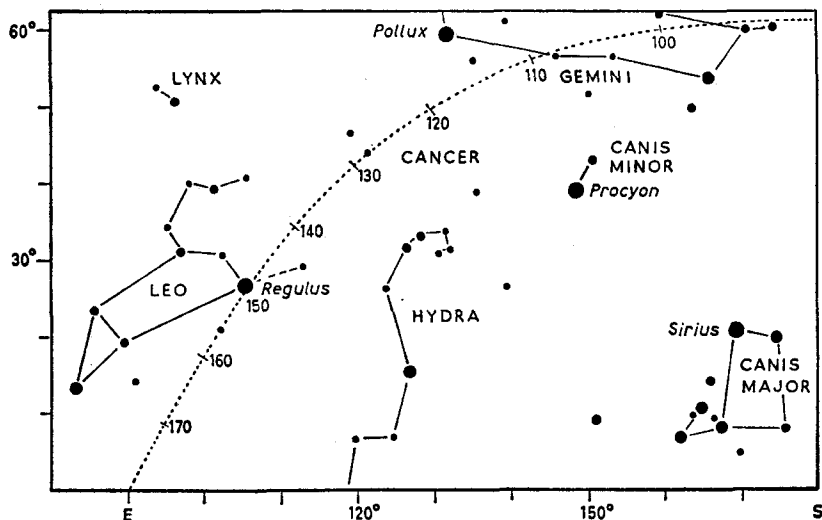
The scale is the same on all the charts (approximately 25 degrees to the inch), but the overhead stars are plotted as a true map on a conical projection, and are not simple graphs like the main charts.

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## 11

October 6 at 5<sup>h</sup>  
November 6 at 3<sup>h</sup>  
December 6 at 1<sup>h</sup>  
January 6 at 23<sup>h</sup>  
February 6 at 21<sup>h</sup>

October 21 at 4<sup>h</sup>  
November 21 at 2<sup>h</sup>  
December 21 at midnight  
January 21 at 22<sup>h</sup>  
February 21 at 20<sup>h</sup>

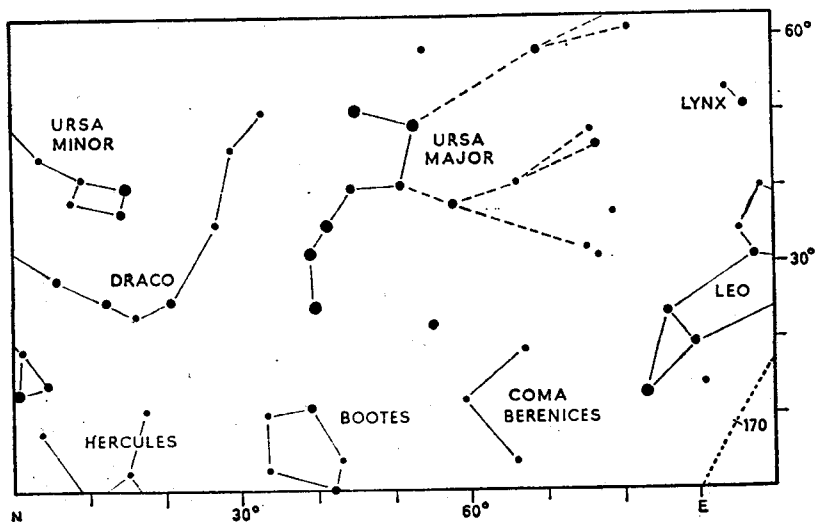
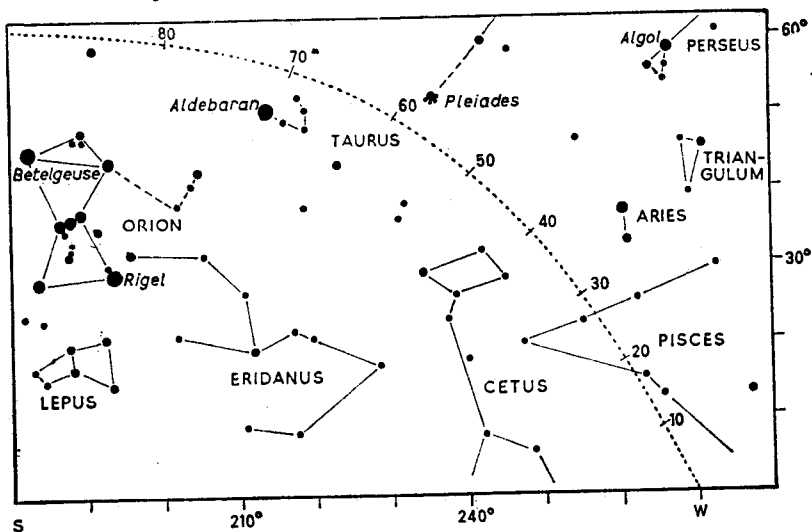


# THE STAR CHARTS

October 6 at 5<sup>h</sup>  
 November 6 at 3<sup>h</sup>  
 December 6 at 1<sup>h</sup>  
 January 6 at 23<sup>h</sup>  
 February 6 at 21<sup>h</sup>

October 21 at 4<sup>h</sup>  
 November 21 at 2<sup>h</sup>  
 December 21 at midnight  
 January 21 at 22<sup>h</sup>  
 February 21 at 20<sup>h</sup>

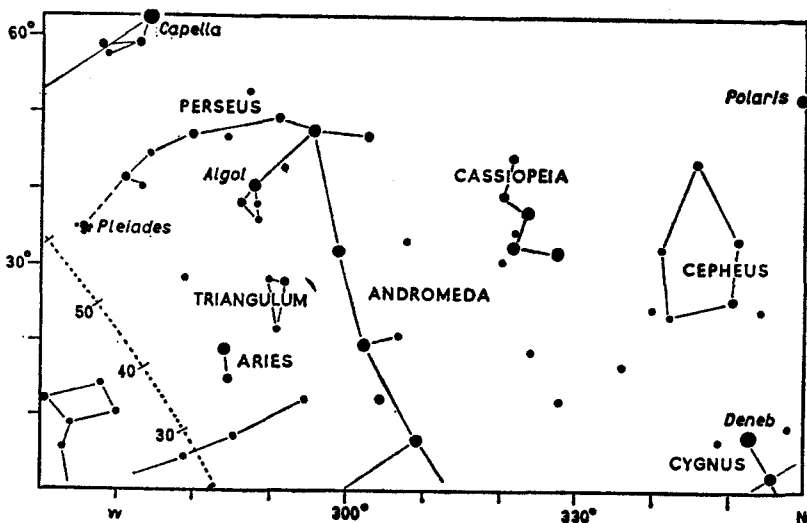
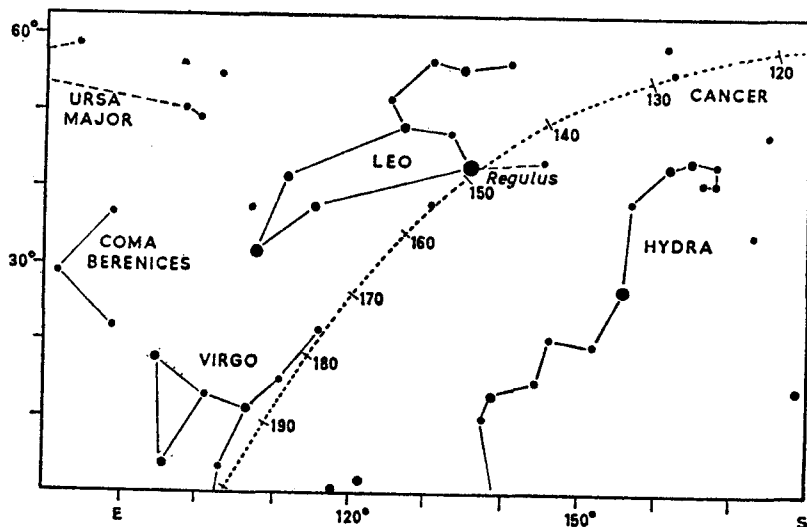
# 1R



2L

November 6 at 5<sup>h</sup>  
 December 6 at 3<sup>h</sup>  
 January 6 at 1<sup>h</sup>  
 February 6 at 23<sup>h</sup>  
 March 6 at 21<sup>h</sup>

November 21 at 4<sup>h</sup>  
 December 21 at 2<sup>h</sup>  
 January 21 at midnight  
 February 21 at 22<sup>h</sup>  
 March 21 at 20<sup>h</sup>

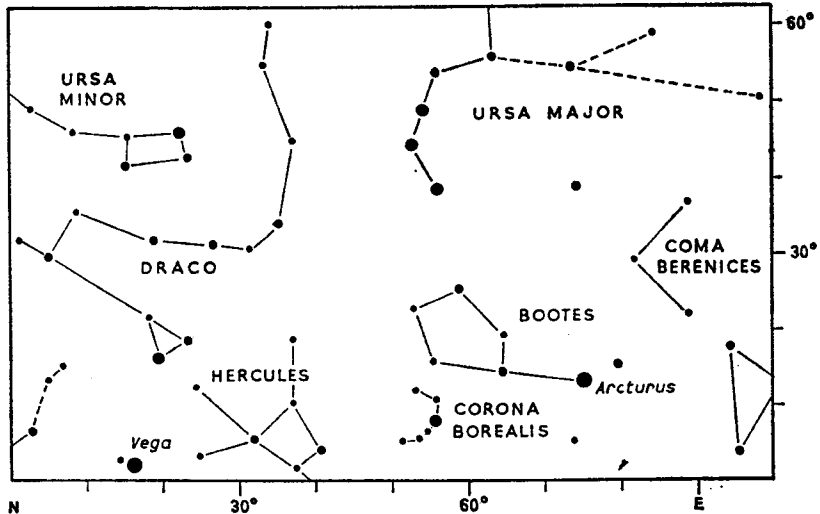
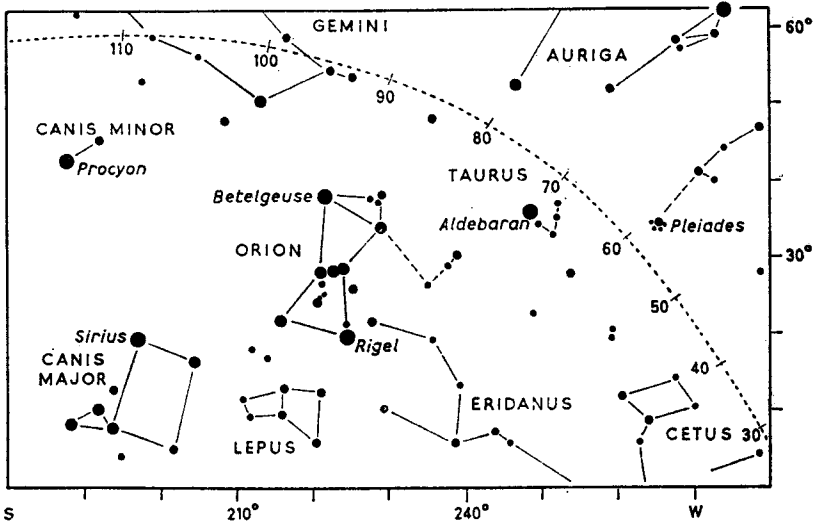


# THE STAR CHARTS

November 6 at 5<sup>h</sup>  
 December 6 at 3<sup>h</sup>  
 January 6 at 1<sup>h</sup>  
 February 6 at 23<sup>h</sup>  
 March 6 at 21<sup>h</sup>

November 21 at 4<sup>h</sup>  
 December 21 at 2<sup>h</sup>  
 January 21 at midnight  
 February 21 at 22<sup>h</sup>  
 March 21 at 20<sup>h</sup>

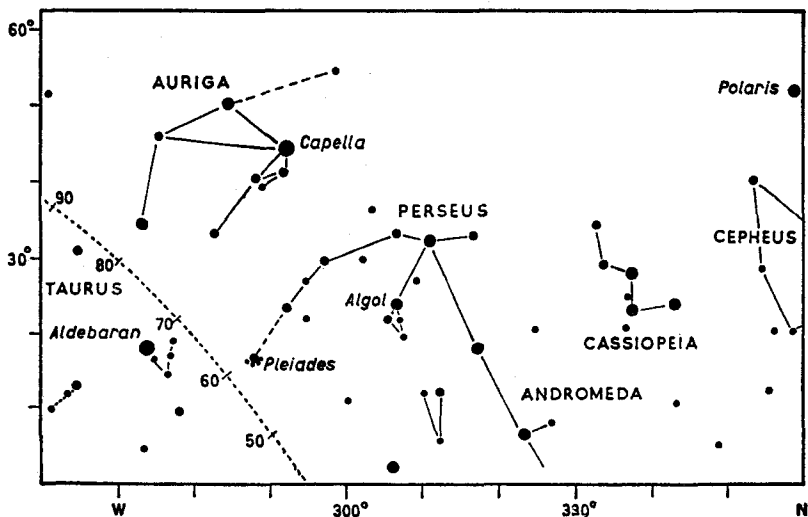
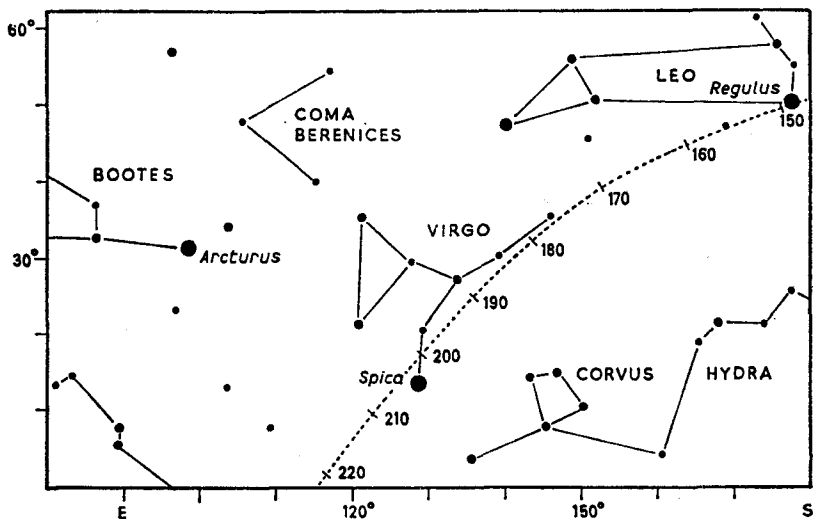
## 2R



3L

December 6 at 5<sup>h</sup>  
January 6 at 3<sup>h</sup>  
February 6 at 1<sup>h</sup>  
March 6 at 23<sup>h</sup>  
April 6 at 21<sup>h</sup>

December 21 at 4<sup>h</sup>  
January 21 at 2<sup>h</sup>  
February 21 at midnight  
March 21 at 22<sup>h</sup>  
April 21 at 20<sup>h</sup>

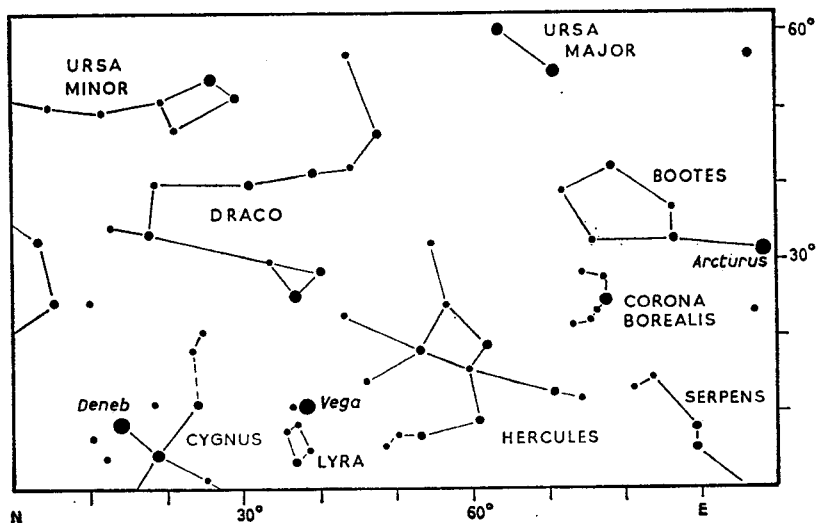
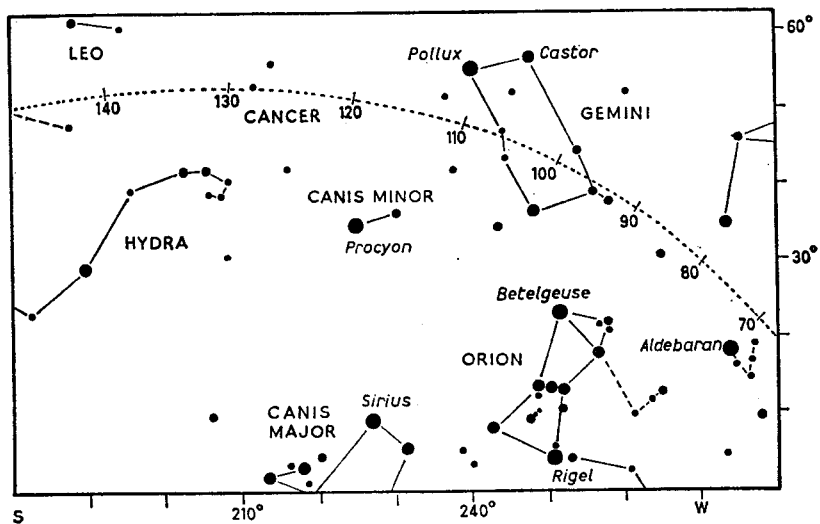


# THE STAR CHARTS

December 6 at 5<sup>h</sup>  
 January 6 at 3<sup>h</sup>  
 February 6 at 1<sup>h</sup>  
 March 6 at 23<sup>h</sup>  
 April 6 at 21<sup>h</sup>

December 21 at 4<sup>h</sup>  
 January 21 at 2<sup>h</sup>  
 February 21 at midnight  
 March 21 at 22<sup>h</sup>  
 April 21 at 20<sup>h</sup>

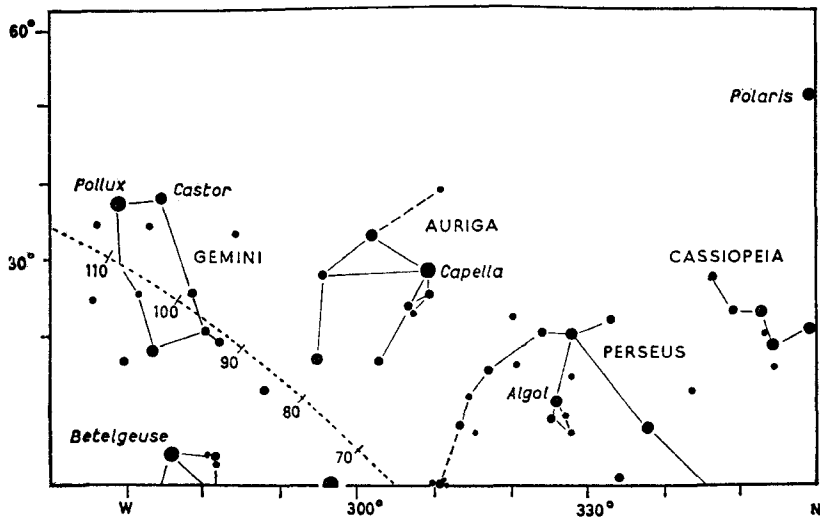
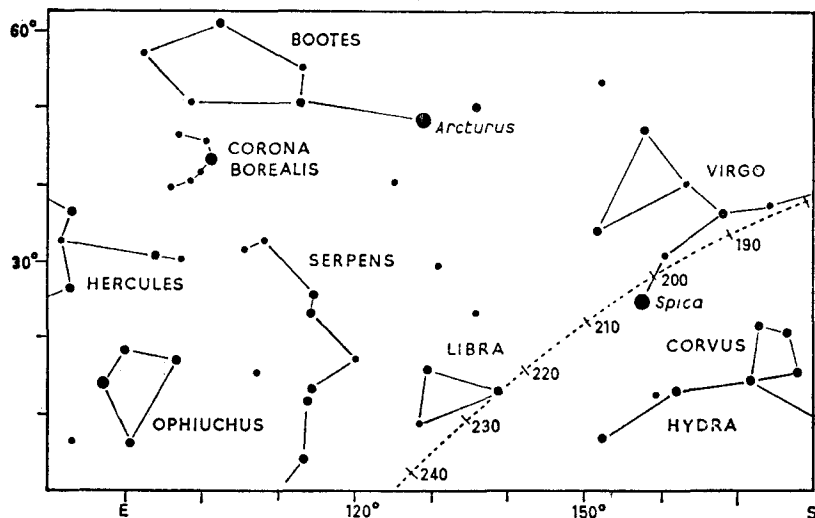
## 3R



**4L**

January 6 at 5<sup>h</sup>  
 February 6 at 3<sup>h</sup>  
 March 6 at 1<sup>h</sup>  
 April 6 at 23<sup>h</sup>  
 May 6 at 21<sup>h</sup>

January 21 at 4<sup>h</sup>  
 February 21 at 2<sup>h</sup>  
 March 21 at midnight  
 April 21 at 22<sup>h</sup>  
 May 21 at 20<sup>h</sup>

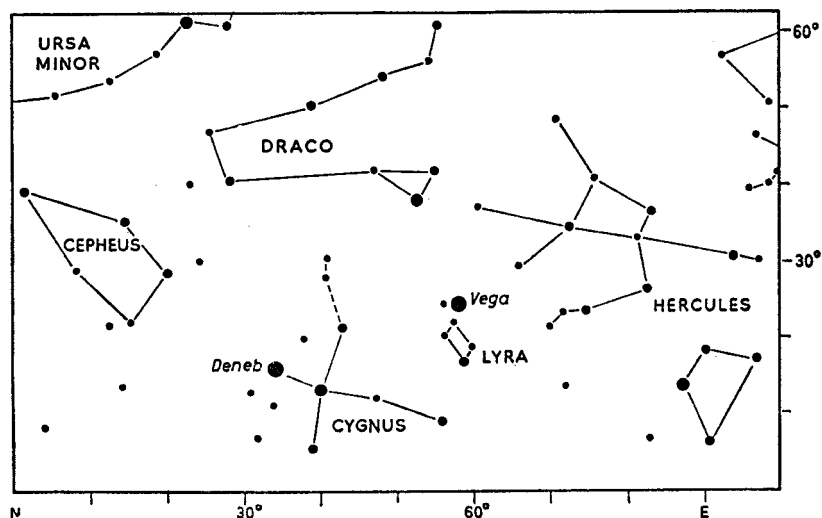
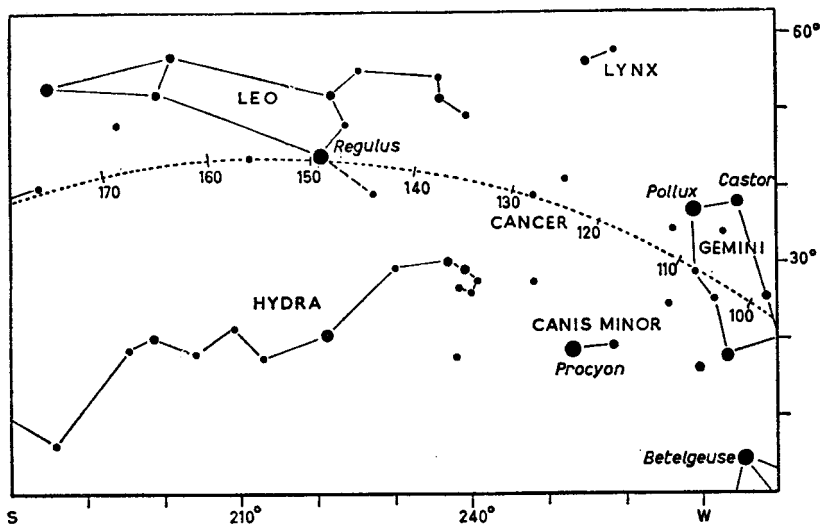


# THE STAR CHARTS

January 6 at 5<sup>h</sup>  
 February 6 at 3<sup>h</sup>  
 March 6 at 1<sup>h</sup>  
 April 6 at 23<sup>h</sup>  
 May 6 at 21<sup>h</sup>

January 21 at 4<sup>h</sup>  
 February 21 at 2<sup>h</sup>  
 March 21 at midnight  
 April 21 at 22<sup>h</sup>  
 May 21 at 20<sup>h</sup>

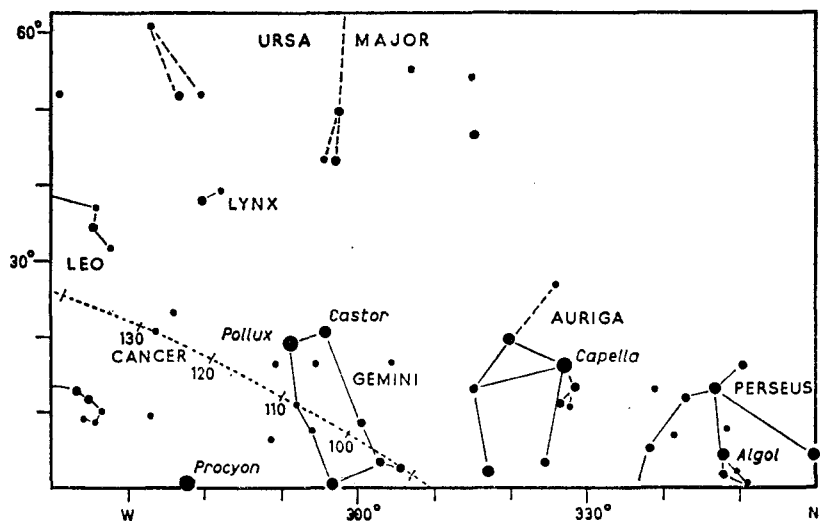
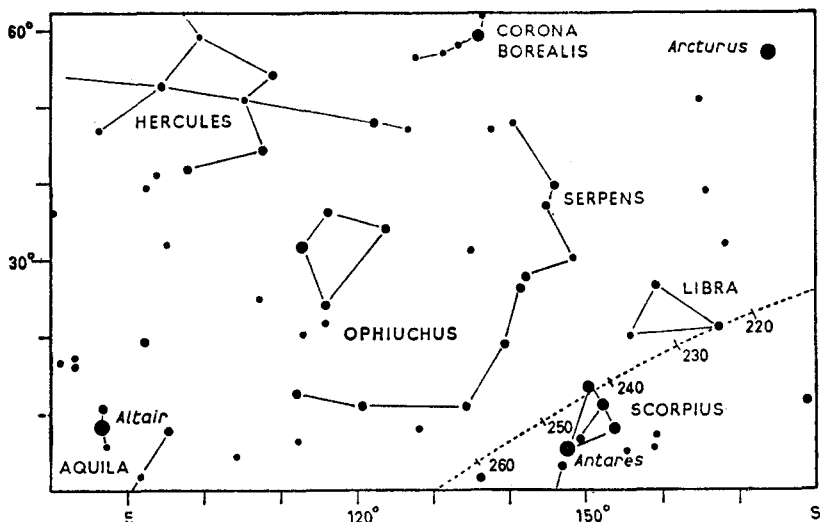
## 4R



**5L**

January 6 at 7<sup>h</sup>  
 February 6 at 5<sup>h</sup>  
 March 6 at 3<sup>h</sup>  
 April 6 at 1<sup>h</sup>  
 May 6 at 23<sup>h</sup>

January 21 at 6<sup>h</sup>  
 February 21 at 4<sup>h</sup>  
 March 21 at 2<sup>h</sup>  
 April 21 at midnight  
 May 21 at 22<sup>h</sup>

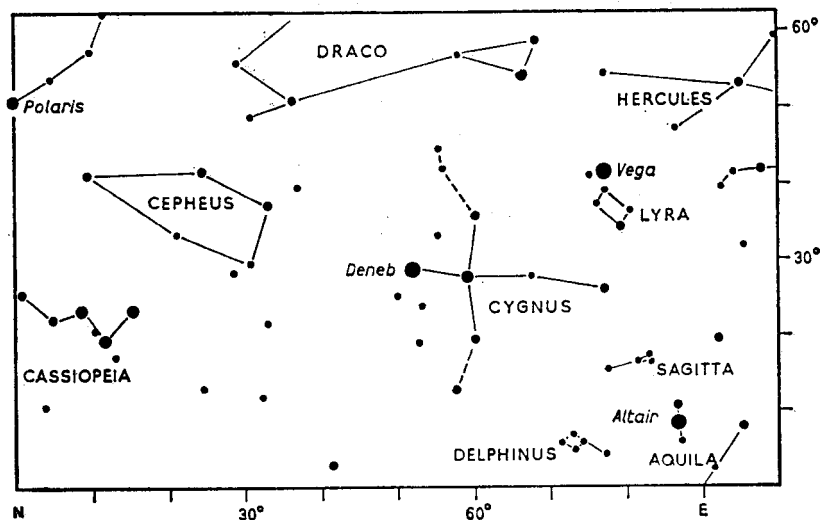
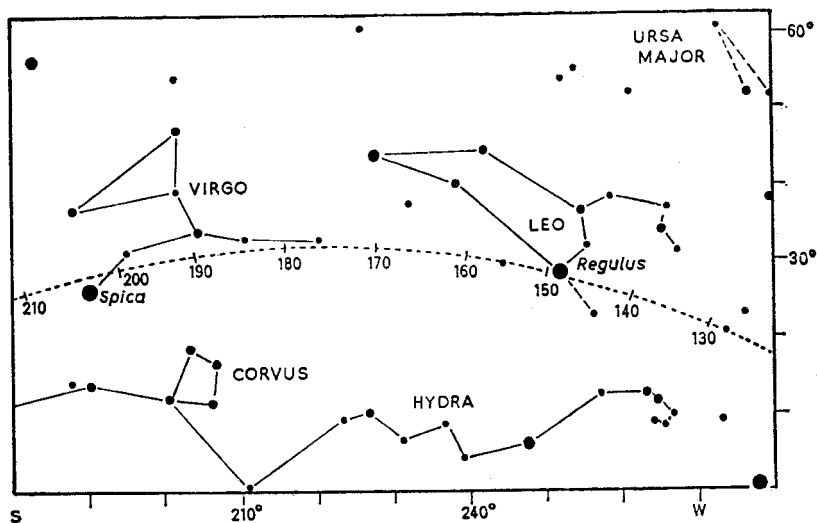


# THE STAR CHARTS

January 6 at 7<sup>h</sup>  
 February 6 at 5<sup>h</sup>  
 March 6 at 3<sup>h</sup>  
 April 6 at 1<sup>h</sup>  
 May 6 at 23<sup>h</sup>

January 21 at 6<sup>h</sup>  
 February 21 at 4<sup>h</sup>  
 March 21 at 2<sup>h</sup>  
 April 21 at midnight  
 May 21 at 22<sup>h</sup>

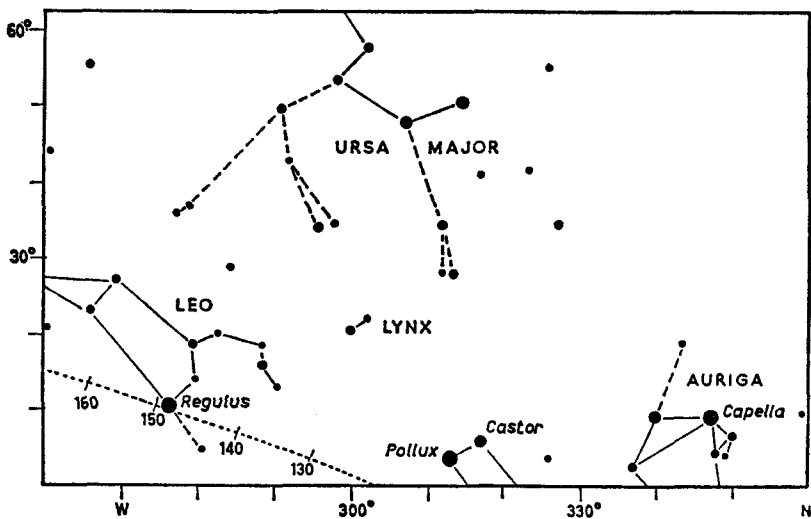
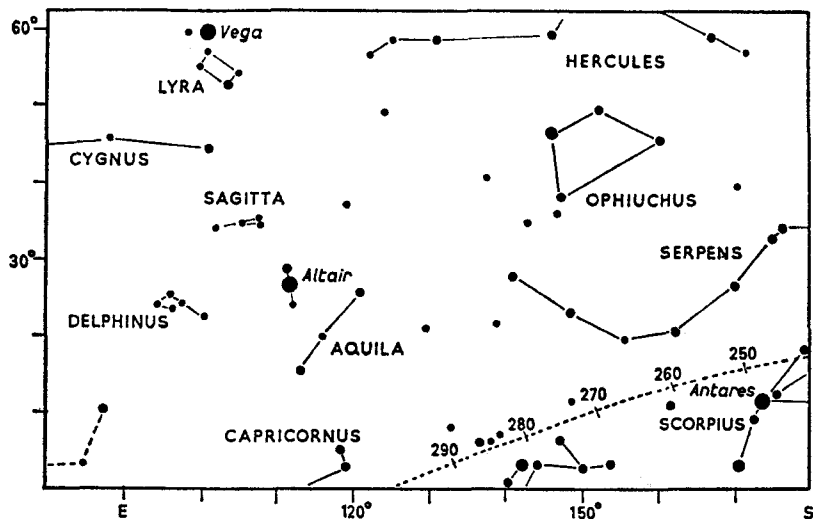
## 5R



6L

March 6 at 5<sup>h</sup>  
 April 6 at 3<sup>h</sup>  
 May 6 at 1<sup>h</sup>  
 June 6 at 23<sup>h</sup>  
 July 6 at 21<sup>h</sup>

March 21 at 4<sup>h</sup>  
 April 21 at 2<sup>h</sup>  
 May 21 at midnight  
 June 21 at 22<sup>h</sup>  
 July 21 at 20<sup>h</sup>

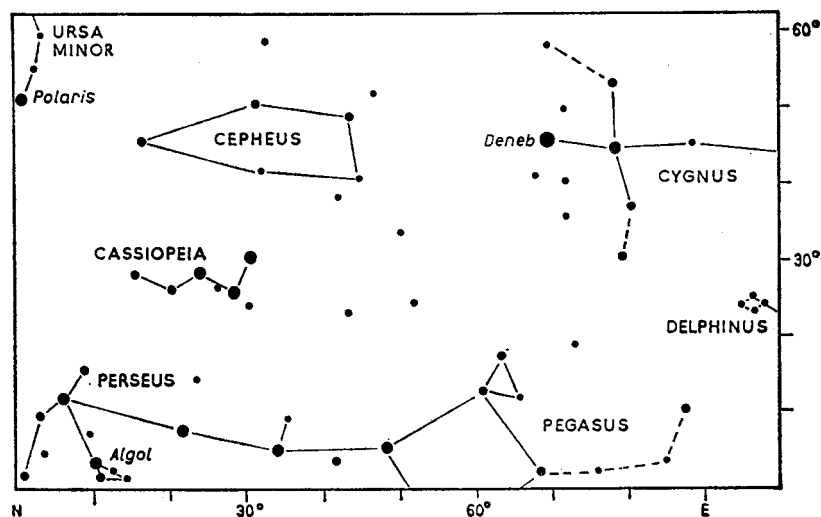
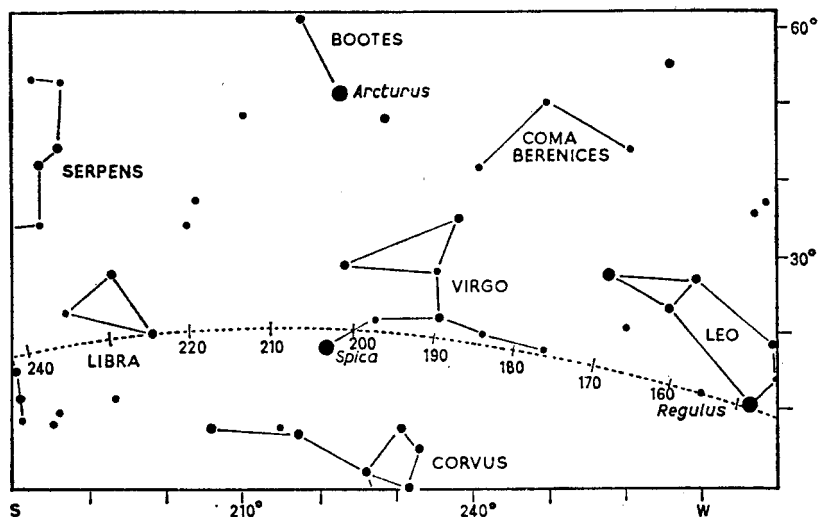


# THE STAR CHARTS

March 6 at 5<sup>h</sup>  
 April 6 at 3<sup>h</sup>  
 May 6 at 1<sup>h</sup>  
 June 6 at 23<sup>h</sup>  
 July 6 at 21<sup>h</sup>

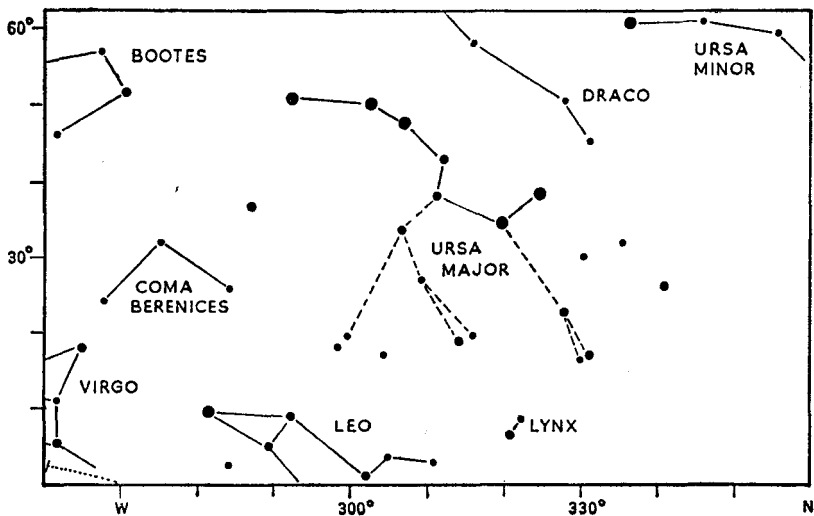
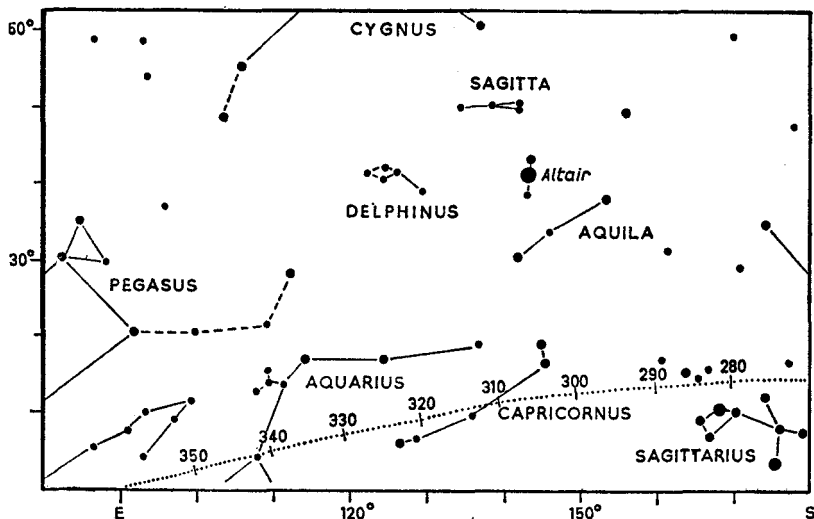
March 21 at 4<sup>h</sup>  
 April 21 at 2<sup>h</sup>  
 May 21 at midnight  
 June 21 at 22<sup>h</sup>  
 July 21 at 20<sup>h</sup>

## 6R



7L

|                                |                                 |
|--------------------------------|---------------------------------|
| May 6 at 3 <sup>h</sup>        | May 21 at 2 <sup>h</sup>        |
| June 6 at 1 <sup>h</sup>       | June 21 at midnight             |
| July 6 at 23 <sup>h</sup>      | July 21 at 22 <sup>h</sup>      |
| August 6 at 21 <sup>h</sup>    | August 21 at 20 <sup>h</sup>    |
| September 6 at 19 <sup>h</sup> | September 21 at 18 <sup>h</sup> |

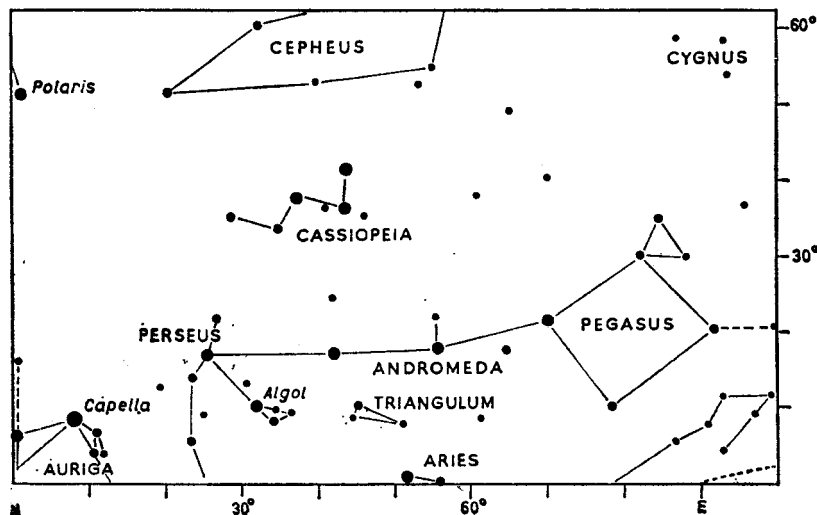
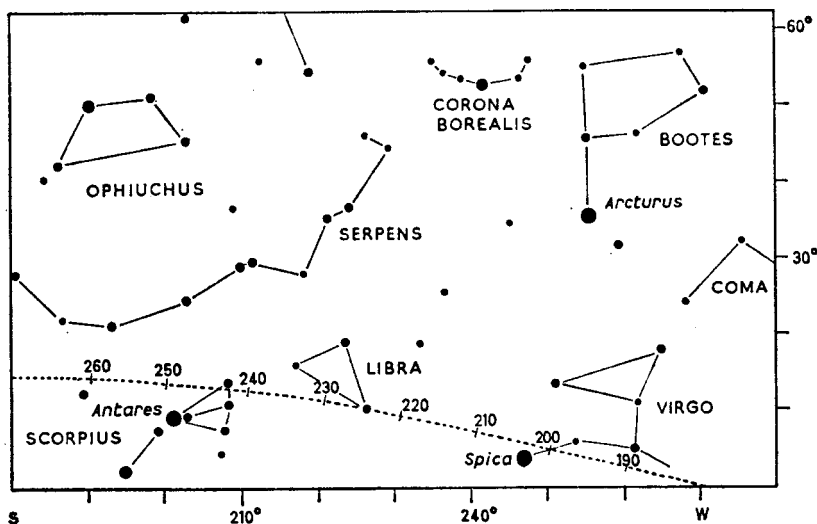


# THE STAR CHARTS

May 6 at 3<sup>h</sup>  
 June 6 at 1<sup>h</sup>  
 July 6 at 23<sup>h</sup>  
 August 6 at 21<sup>h</sup>  
 September 6 at 19<sup>h</sup>

May 21 at 2<sup>h</sup>  
 June 21 at midnight  
 July 21 at 22<sup>h</sup>  
 August 21 at 20<sup>h</sup>  
 September 21 at 18<sup>h</sup>

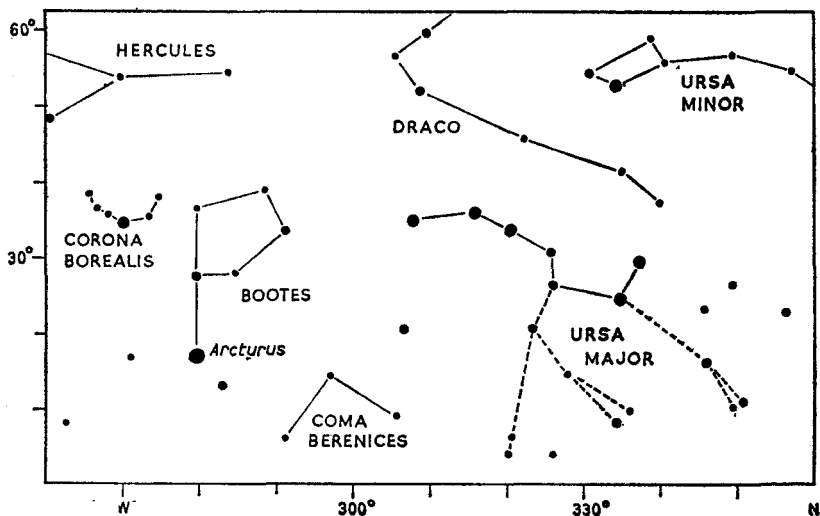
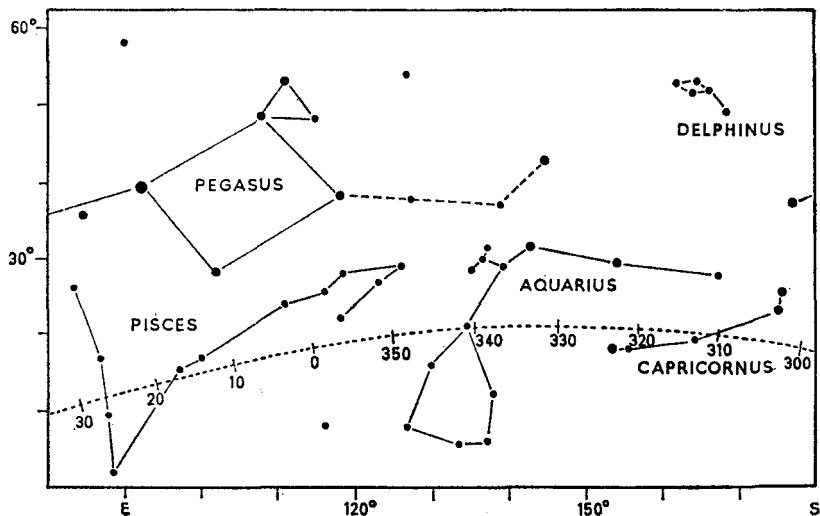
# 7R



8L

July 6 at 1<sup>h</sup>  
 August 6 at 23<sup>h</sup>  
 September 6 at 21<sup>h</sup>  
 October 6 at 19<sup>h</sup>  
 November 6 at 17<sup>h</sup>

July 21 at midnight  
 August 21 at 22<sup>h</sup>  
 September 21 at 20<sup>h</sup>  
 October 21 at 18<sup>h</sup>  
 November 21 at 16<sup>h</sup>

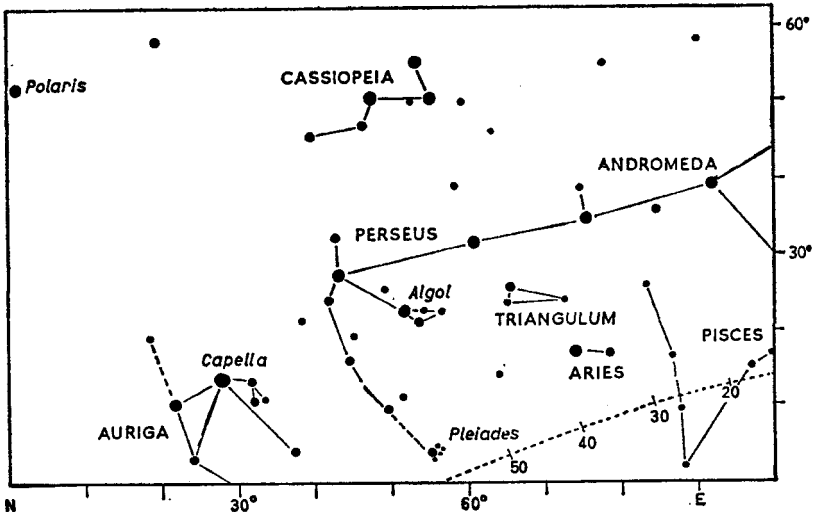
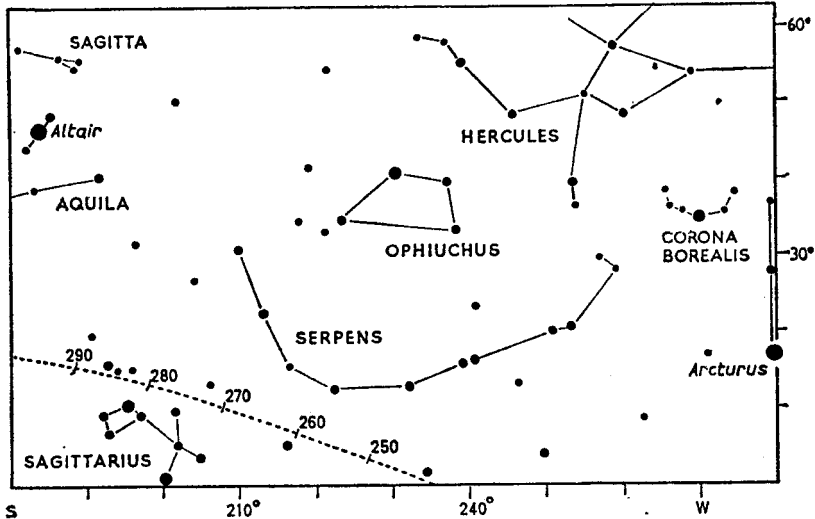


# THE STAR CHARTS

July 6 at 1<sup>h</sup>  
 August 6 at 23<sup>h</sup>  
 September 6 at 21<sup>h</sup>  
 October 6 at 19<sup>h</sup>  
 November 6 at 17<sup>h</sup>

July 21 at midnight  
 August 21 at 22<sup>h</sup>  
 September 21 at 20<sup>h</sup>  
 October 21 at 18<sup>h</sup>  
 November 21 at 16<sup>h</sup>

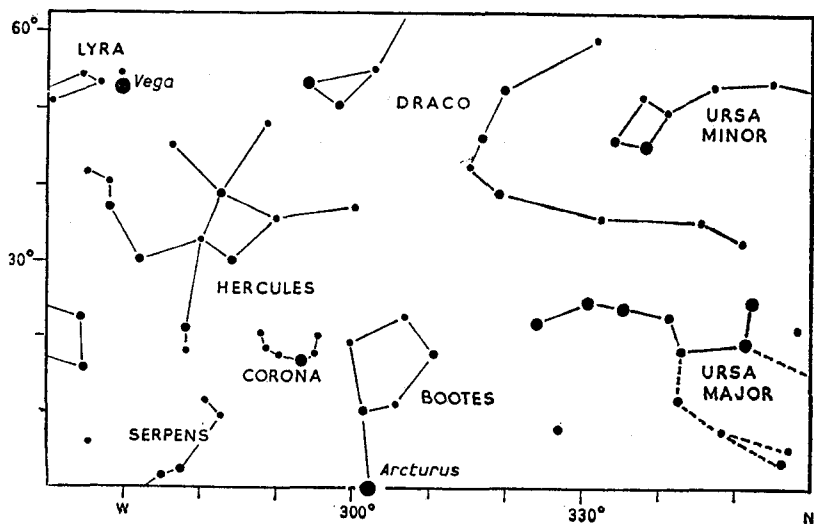
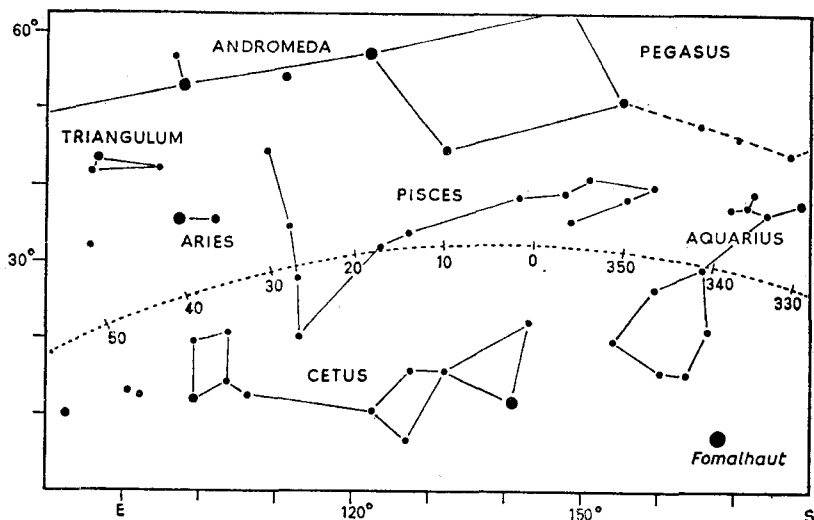
## 8R



**9L**

August 6 at 1<sup>h</sup>  
 September 6 at 23<sup>h</sup>  
 October 6 at 21<sup>h</sup>  
 November 6 at 19<sup>h</sup>  
 December 6 at 17<sup>h</sup>

August 21 at midnight  
 September 21 at 22<sup>h</sup>  
 October 21 at 20<sup>h</sup>  
 November 21 at 18<sup>h</sup>  
 December 21 at 16<sup>h</sup>

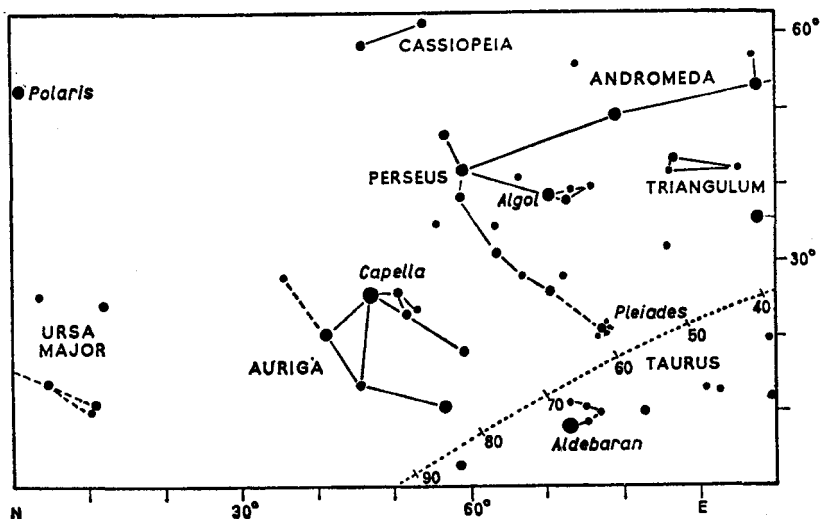
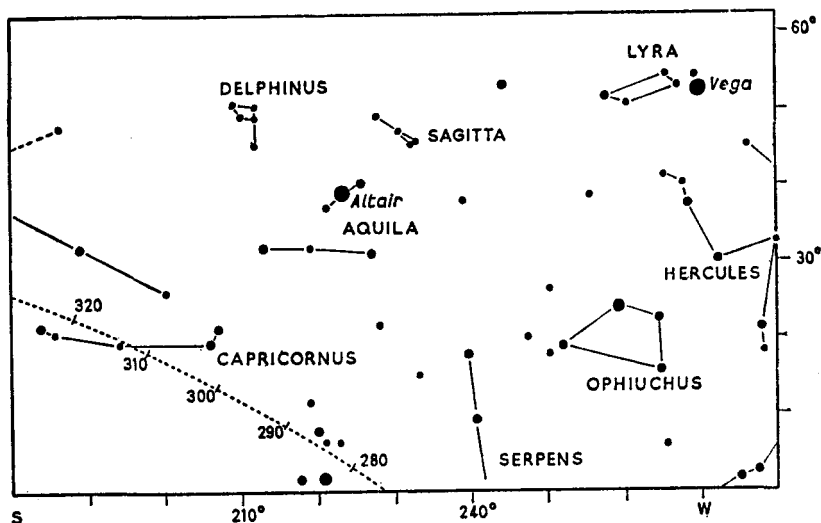


# THE STAR CHARTS

August 6 at 1<sup>h</sup>  
 September 6 at 23<sup>h</sup>  
 October 6 at 21<sup>h</sup>  
 November 6 at 19<sup>h</sup>  
 December 6 at 17<sup>h</sup>

August 21 at midnight  
 September 21 at 22<sup>h</sup>  
 October 21 at 20<sup>h</sup>  
 November 21 at 18<sup>h</sup>  
 December 21 at 16<sup>h</sup>

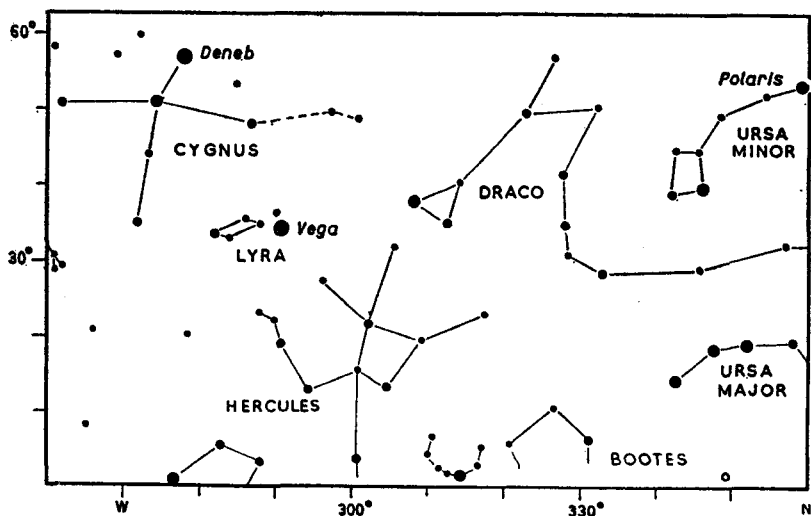
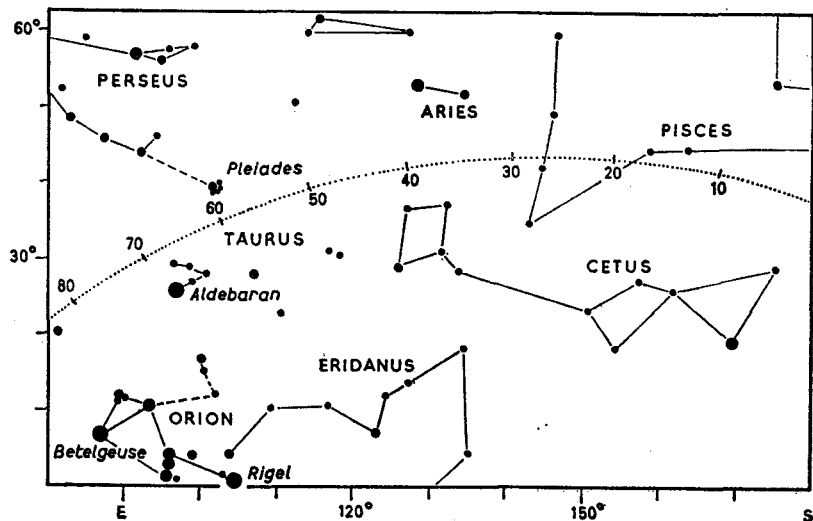
## 9R



**10L**

August 6 at 3<sup>h</sup>  
 September 6 at 1<sup>h</sup>  
 October 6 at 23<sup>h</sup>  
 November 6 at 21<sup>h</sup>  
 December 6 at 19<sup>h</sup>

August 21 at 2<sup>h</sup>  
 September 21 at midnight  
 October 21 at 22<sup>h</sup>  
 November 21 at 20<sup>h</sup>  
 December 21 at 18<sup>h</sup>

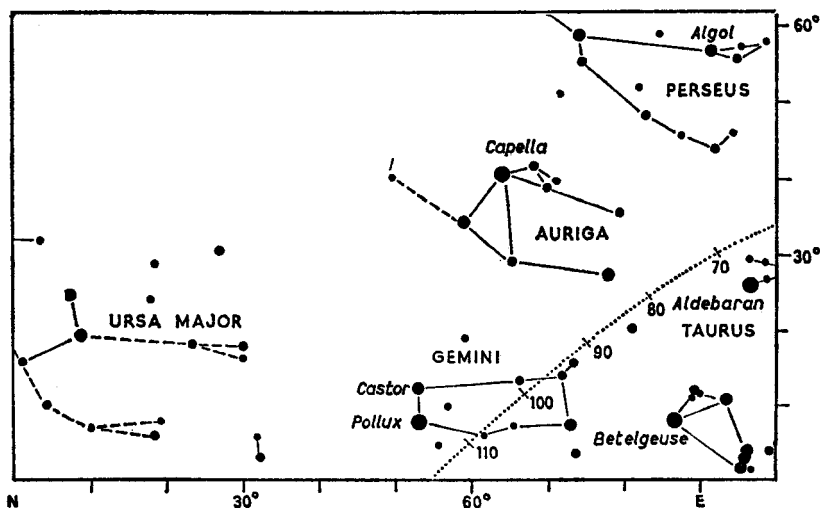
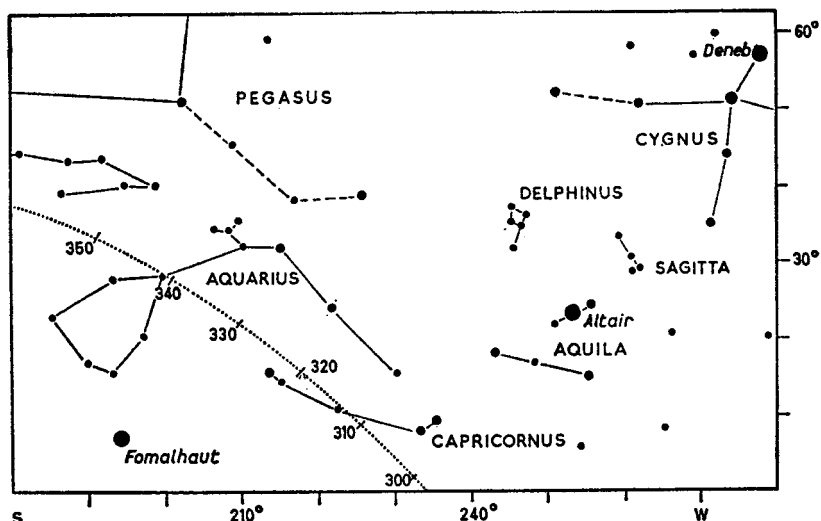


# THE STAR CHARTS

August 6 at 3<sup>h</sup>  
 September 6 at 1<sup>h</sup>  
 October 6 at 23<sup>h</sup>  
 November 6 at 21<sup>h</sup>  
 December 6 at 19<sup>h</sup>

August 21 at 2<sup>h</sup>  
 September 21 at midnight  
 October 21 at 22<sup>h</sup>  
 November 21 at 20<sup>h</sup>  
 December 21 at 18<sup>h</sup>

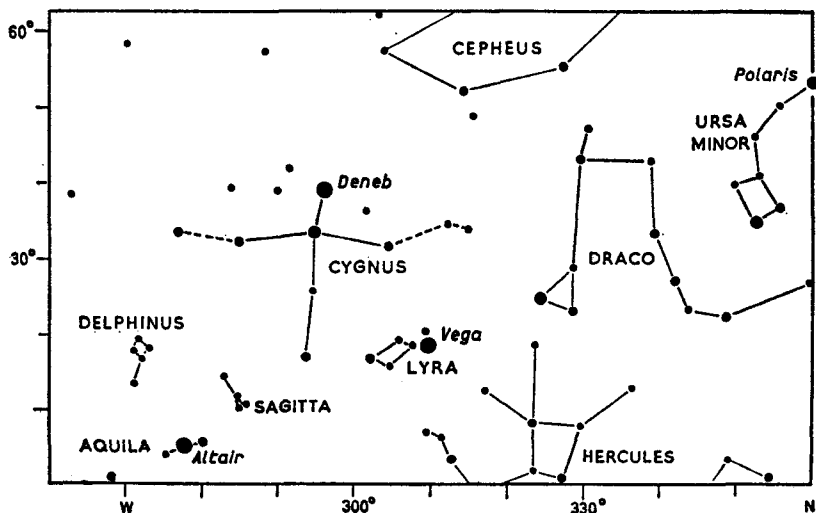
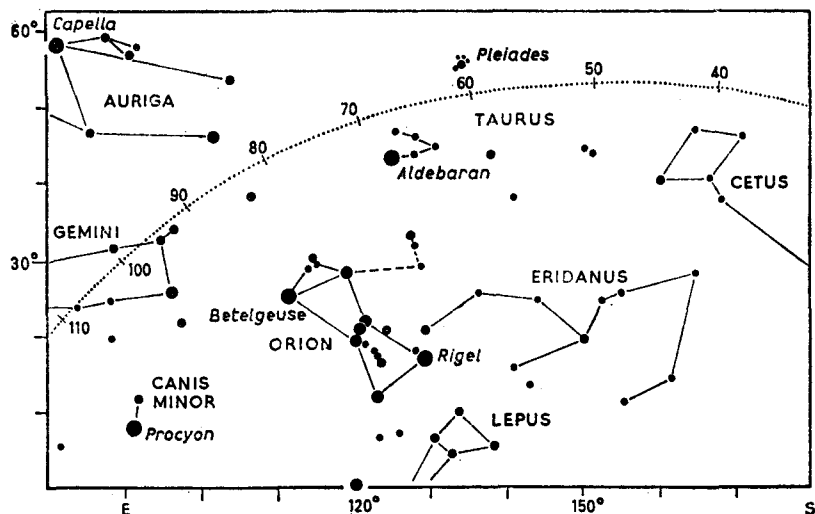
## 10R



# 1976 YEARBOOK OF ASTRONOMY

## 11L

|                               |                                |
|-------------------------------|--------------------------------|
| September 6 at 3 <sup>h</sup> | September 21 at 2 <sup>h</sup> |
| October 6 at 1 <sup>h</sup>   | October 21 at midnight         |
| November 6 at 23 <sup>h</sup> | November 21 at 22 <sup>h</sup> |
| December 6 at 21 <sup>h</sup> | December 21 at 20 <sup>h</sup> |
| January 6 at 19 <sup>h</sup>  | January 21 at 18 <sup>h</sup>  |

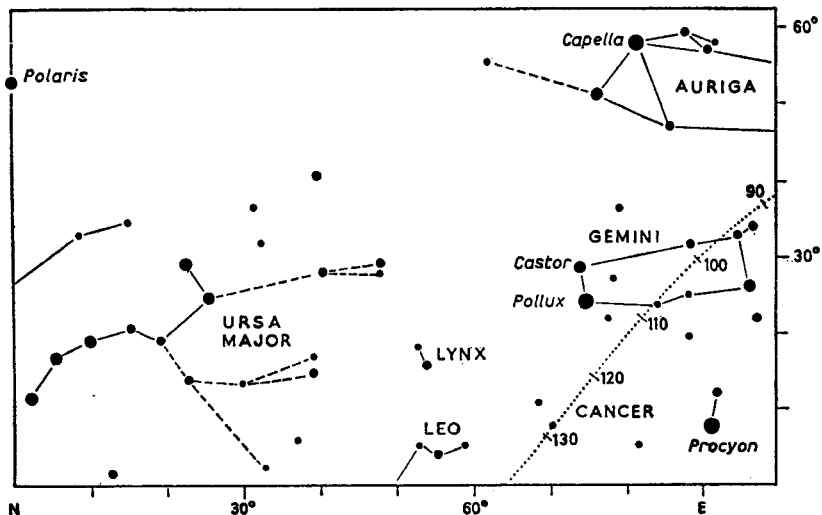
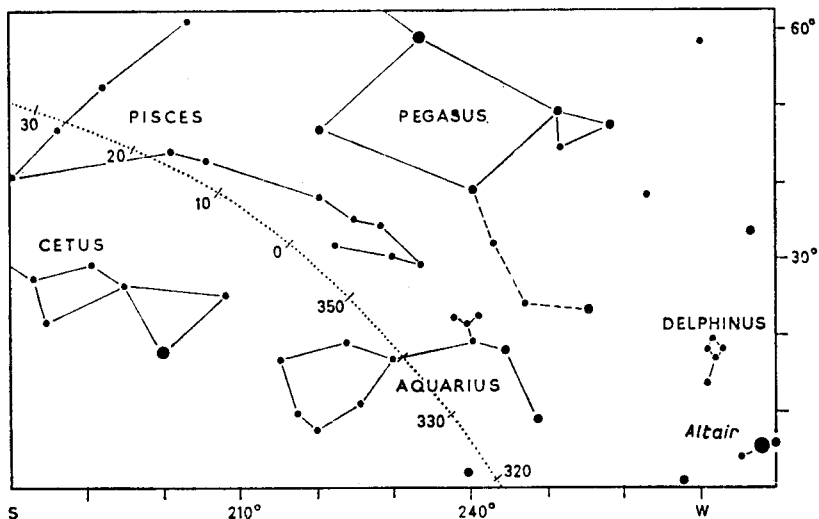


# THE STAR CHARTS

September 6 at 3<sup>h</sup>  
 October 6 at 1<sup>h</sup>  
 November 6 at 23<sup>h</sup>  
 December 6 at 21<sup>h</sup>  
 January 6 at 19<sup>h</sup>

September 21 at 2<sup>h</sup>  
 October 21 at midnight  
 November 21 at 22<sup>h</sup>  
 December 21 at 20<sup>h</sup>  
 January 21 at 18<sup>h</sup>

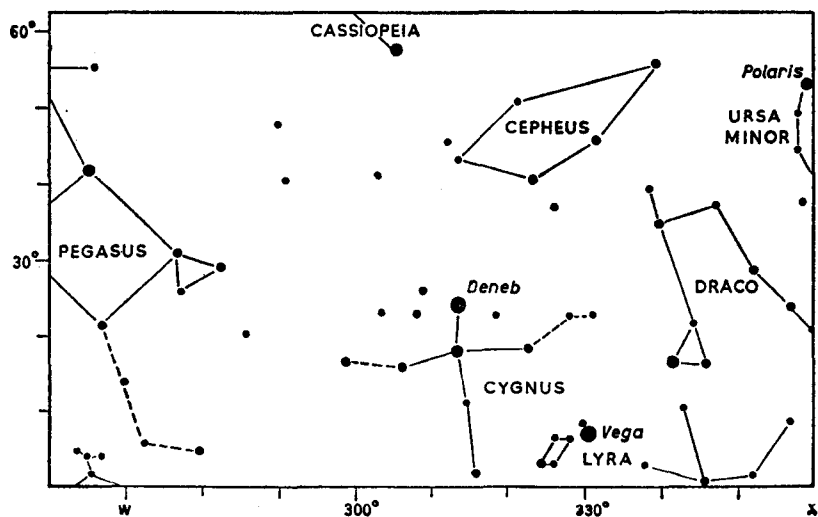
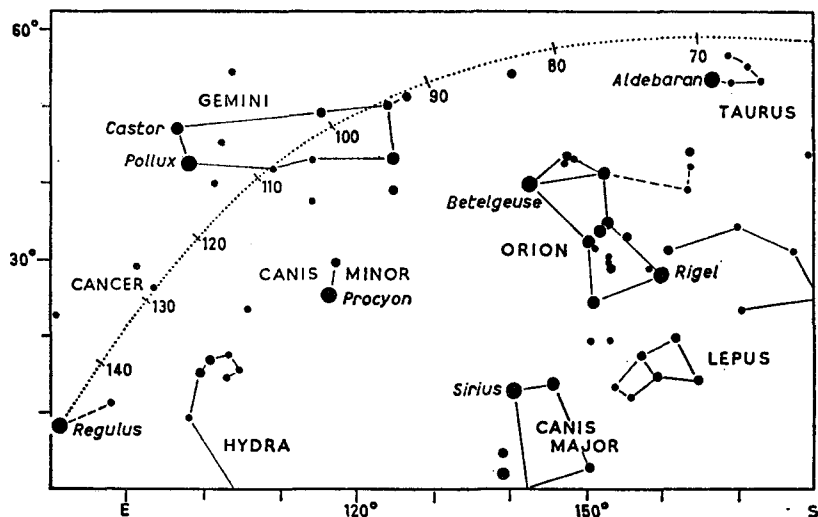
# 11R



**12L**

October 6 at 3<sup>h</sup>  
 November 6 at 1<sup>h</sup>  
 December 6 at 23<sup>h</sup>  
 January 6 at 21<sup>h</sup>  
 February 6 at 19<sup>h</sup>

October 21 at 2<sup>h</sup>  
 November 21 at midnight  
 December 21 at 22<sup>h</sup>  
 January 21 at 20<sup>h</sup>  
 February 21 at 18<sup>h</sup>

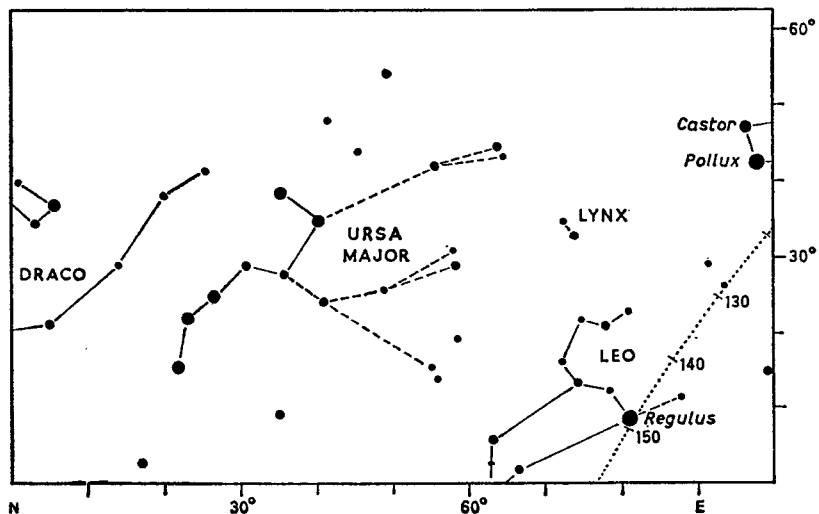
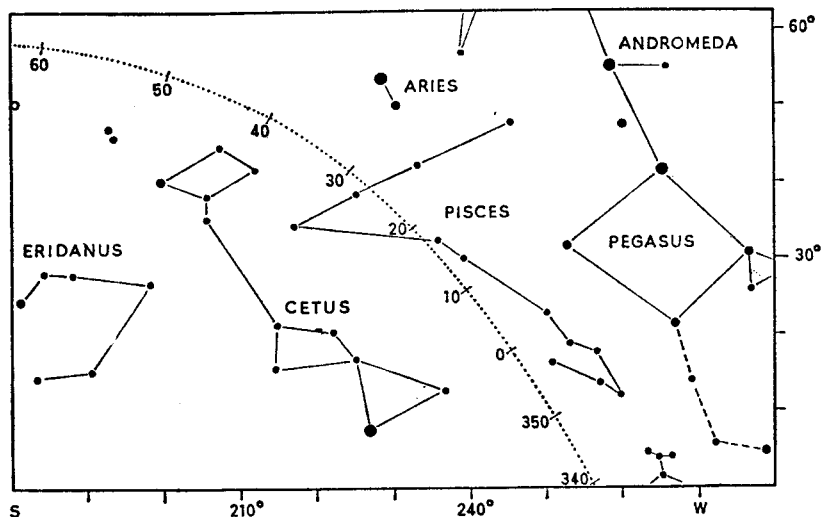


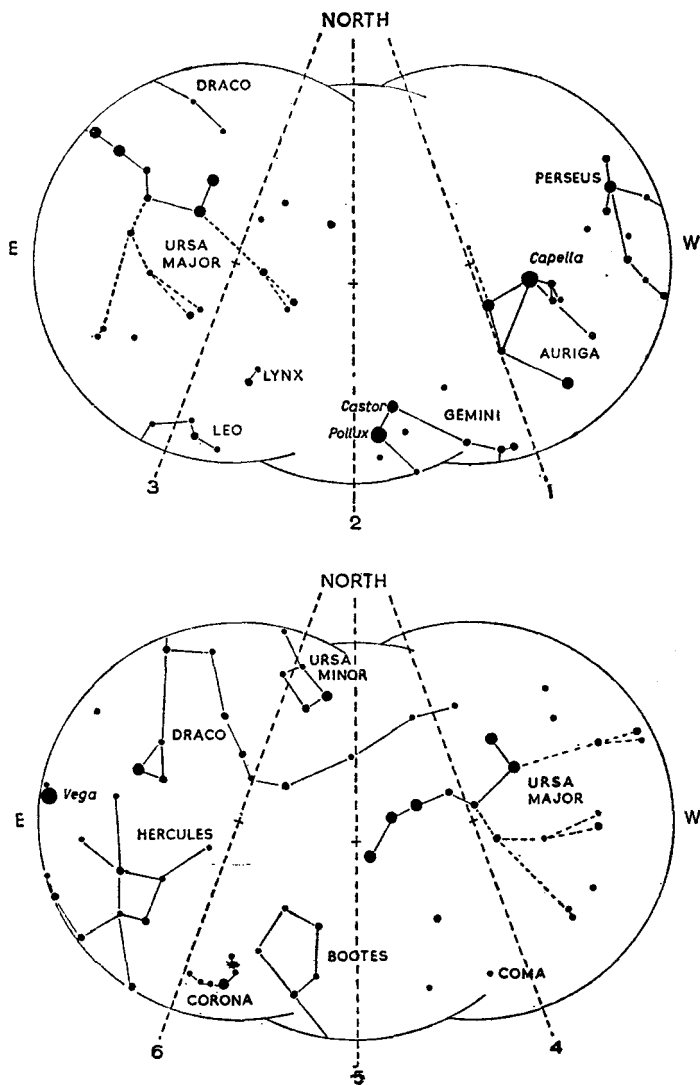
# THE STAR CHARTS

## 12R

October 6 at 3<sup>h</sup>  
 November 6 at 1<sup>h</sup>  
 December 6 at 23<sup>h</sup>  
 January 6 at 21<sup>h</sup>  
 February 6 at 19<sup>h</sup>

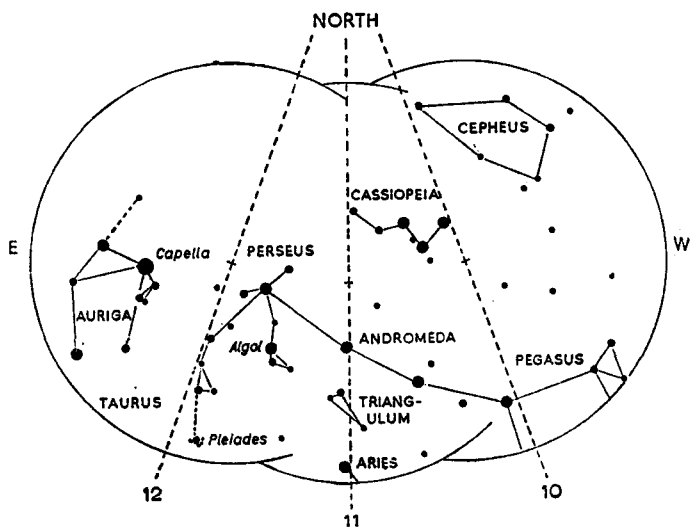
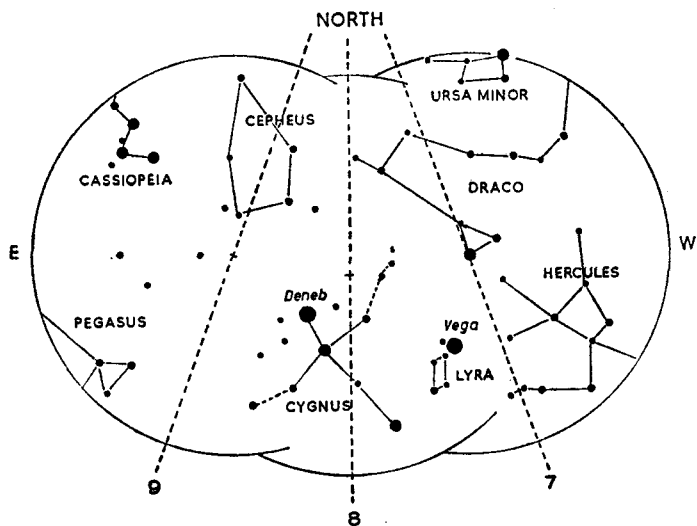
October 21 at 2<sup>h</sup>  
 November 21 at midnight  
 December 21 at 22<sup>h</sup>  
 January 21 at 20<sup>h</sup>  
 February 21 at 18<sup>h</sup>





*Overhead stars*

# THE STAR CHARTS



*Overhead stars*



## Events in 1976

### ECLIPSES

In 1976 there will be three eclipses, two of the Sun and one of the Moon.

29 April – an annular eclipse of the Sun, visible in Asia, North Africa, and Europe.

13 May – a partial eclipse of the Moon, visible in Australasia, Asia, Europe, and Africa.

23 October – a total eclipse of the Sun, visible in Australia, Asia, and East Africa.

### THE PLANETS

*Mercury* may be seen most easily as an evening star near eastern elongation on 28 April, and as a morning star at western elongation on 7 October.

*Venus* will not make a very outstanding display in 1976. It is a morning star for the first half of the year, and becomes an evening star after superior conjunction on 18 June.

*Mars* will be seen as an evening star for the greater part of the year, and is in conjunction with the Sun on 25 November.

*Jupiter* is in conjunction on 27 April and comes to opposition in Taurus on 18 November.

*Saturn* is at opposition in Cancer on 20 January, and in conjunction on 29 July.

*Uranus* is at opposition on 25 April on the borders of Virgo and Libra.

*Neptune* is at opposition in Scorpius on 3 June.

*Pluto* is at opposition on 30 March.

## The Planets in 1976

| DATE                |         | <i>Venus</i> | <i>Mars</i> | <i>Jupiter</i> | <i>Saturn</i> | <i>Uranus</i> | <i>Neptune</i> |
|---------------------|---------|--------------|-------------|----------------|---------------|---------------|----------------|
| January             | 6       | 246°         | 76°         | 16°            | 121°          | 217°          | 253°           |
|                     | 21      | 264          | 74          | 18             | 120           | 217           | 253            |
| February            | 6       | 283          | 76          | 20             | 118           | 217           | 254            |
|                     | 21      | 302          | 80          | 23             | 117           | 217           | 254            |
| March               | 6       | 319          | 85          | 26             | 117           | 217           | 254            |
|                     | 21      | 338          | 91          | 29             | 116           | 217           | 254            |
| April               | 6       | 358          | 99          | 33             | 116           | 216           | 254            |
|                     | 21      | 16           | 106         | 36             | 117           | 215           | 254            |
| May                 | 6       | 34           | 115         | 40             | 118           | 215           | 254            |
|                     | 21      | 53           | 123         | 43             | 119           | 214           | 253            |
| June                | 6       | 72           | 132         | 47             | 120           | 214           | 253            |
|                     | 21      | 91           | 141         | 50             | 122           | 213           | 252            |
| July                | 6       | 109          | 150         | 53             | 124           | 213           | 252            |
|                     | 21      | 128          | 159         | 56             | 126           | 213           | 252            |
| August              | 6       | 148          | 169         | 58             | 128           | 214           | 251            |
|                     | 21      | 166          | 178         | 60             | 130           | 214           | 251            |
| September           | 6       | 186          | 188         | 61             | 132           | 215           | 251            |
|                     | 21      | 204          | 198         | 61             | 133           | 215           | 252            |
| October             | 6       | 222          | 208         | 61             | 135           | 216           | 252            |
|                     | 21      | 240          | 218         | 60             | 136           | 217           | 252            |
| November            | 6       | 260          | 229         | 58             | 137           | 218           | 253            |
|                     | 21      | 278          | 240         | 56             | 137           | 219           | 253            |
| December            | 6       | 296          | 251         | 54             | 137           | 220           | 254            |
|                     | 21      | 314          | 262         | 53             | 137           | 221           | 254            |
| <i>Conjunction:</i> | June 18 |              | Nov. 25     | Apr. 27        | July 29       | Oct. 30       | Dec. 5         |
| <i>Opposition:</i>  | —       |              | —           | Nov. 18        | Jan. 20       | Apr. 25       | June 3         |

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The monthly notes must be consulted for the best times at which the planet may be seen.

The positions of the other planets are given in the table on the opposite page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples:

- (1) *What is the bright planet rising to the north of east at about 20<sup>h</sup> at the end of September?*

The lower charts at the foot of 8R and 9R indicate that the longitude of the planet must be about 60°. The table opposite shows that the planet is Jupiter, and the September notes confirm that the planet is then near a stationary point in Taurus.

- (2) *Where may the planet Mars be found in early March?*

The table opposite gives the longitude of Mars at this time as 85°. Charts 1R and 2R show this position, north of the figure of Orion. The planet sets north of west (charts 4L and 5L) at about 3<sup>h</sup>.

## The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon, and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about  $23\frac{1}{2}$  degrees to the equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening star, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the north-west. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For similar reasons, a morning star will be seen at its best on autumn mornings before

## THE PLANETS AND THE ECLIPTIC

sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition and are then in the south at midnight, are best seen when opposition occurs in the winter months. Clearly the summer is the least favourable time to observe the planets, for the ecliptic is always low in the sky on summer nights.

## Notes on the Planets in the monthly diagrams

The following general notes on observing the planets are followed by detailed month-by-month accounts of the behaviour of the planets, and of other interesting phenomena. These monthly notes include diagrams of the apparent movements of the planets at favourable times of the year. Additional notes on other astronomical phenomena will be found on the following pages.

*The inferior planets*, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are then seen as evening stars in the western sky after sunset (at eastern elongations) or as morning stars in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and elongations, always follows the same order, but the intervals between them are not equal. Thus, if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun – that is, to come to superior conjunction – than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

## NOTES ON THE PLANETS IN THE MONTHLY DIAGRAMS

|                                   | <i>Mercury</i> | <i>Venus</i> |
|-----------------------------------|----------------|--------------|
| Inferior conj. to Elongation West | 22 days        | 72 days      |
| Elongation West to Superior conj. | 36 days        | 220 days     |
| Superior conj. to Elongation East | 36 days        | 220 days     |
| Elongation East to Inferior conj. | 22 days        | 72 days      |

The greatest brilliancy of Venus always occurs about a month *before* greatest western elongation (as a morning star), or a month *after* greatest eastern elongation (as an evening star). No such rule can be given for Mercury, because its distance from Sun and Earth can vary over a wide range.

*Mercury* is not likely to be seen unless a clear horizon is available; it is seldom seen as much as 10 degrees above the horizon in the twilight sky. In general, it may be said that the most favourable times for seeing Mercury as an evening star will be in spring, some days before greatest eastern elongation; in autumn it may be seen as a morning star some days after greatest western elongation.

*Venus* is the brightest of the planets, and may be seen on occasions in broad daylight. Like Mercury, it is alternately a morning and an evening star, and will be highest in the sky when it is a morning star in autumn, or an evening star in spring. Venus is seen to best advantage when it comes to greatest eastern elongation in June; it is then well north of the Sun in the spring months and is a brilliant object in the sunset sky over a long period.

*The superior planets*, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning stars after conjunction with the Sun, rising earlier each day until they come to opposition. They will then be in the south at midnight, and visible all night. After opposition, they are evening stars, setting earlier each evening until they set in the west with the Sun at the next conjunction. The interval between conjunctions or between oppositions is greatest for Mars (over two years). At the time of opposition, the planet is nearest the Earth, and therefore at its brightest. This change in brightness is most noticeable

with Mars, whose distance from the Earth can vary considerably; the other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of importance, for at a December opposition the planet will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so make a less impressive appearance.

*Mars*, whose orbit is appreciably eccentric, comes nearest to the Earth at an opposition at the end of August; it may then be brighter even than Jupiter, but rather low in the sky in Aquarius. These favourable oppositions occur every fifteen or seventeen years (1924, 1941, 1956, 1971), but in this country the planet is probably better seen at an opposition in the autumn or winter, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

*Jupiter* is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one Zodiacal constellation to the next.

*Saturn* moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspect of its rings, as well as on the distance from Earth and Sun. The rings are now closing again, and the planet is therefore less bright at each successive opposition.

*Uranus*, *Neptune* and *Pluto* are hardly likely to attract the attention of observers without adequate instruments, but some notes on their present positions in the sky will be found in the March, April and June notes.

## Phases of the Moon, 1976

| <i>New Moon</i> |    |       | <i>First Quarter</i> |    |       | <i>Full Moon</i> |    |       | <i>Last Quarter</i> |    |       |
|-----------------|----|-------|----------------------|----|-------|------------------|----|-------|---------------------|----|-------|
|                 | d  | h m   |                      | d  | h m   |                  | d  | h m   |                     | d  | h m   |
| Jan.            | 1  | 14 40 | Jan.                 | 9  | 12 40 | Jan.             | 17 | 04 47 | Jan.                | 23 | 23 04 |
| Jan.            | 31 | 06 20 | Feb.                 | 8  | 10 05 | Feb.             | 15 | 16 43 | Feb.                | 22 | 08 16 |
| Feb.            | 29 | 23 25 | Mar.                 | 9  | 04 38 | Mar.             | 16 | 02 53 | Mar.                | 22 | 18 54 |
| Mar.            | 30 | 17 08 | Apr.                 | 7  | 19 02 | Apr.             | 14 | 11 49 | Apr.                | 21 | 07 14 |
| Apr.            | 29 | 10 20 | May                  | 7  | 05 17 | May              | 13 | 20 04 | May                 | 20 | 21 22 |
| May             | 29 | 01 47 | June                 | 5  | 12 20 | June             | 12 | 04 15 | June                | 19 | 13 15 |
| June            | 27 | 14 50 | July                 | 4  | 17 28 | July             | 11 | 13 09 | July                | 19 | 06 29 |
| July            | 27 | 01 39 | Aug.                 | 2  | 22 07 | Aug.             | 9  | 23 44 | Aug.                | 18 | 00 13 |
| Aug.            | 25 | 11 01 | Sept.                | 1  | 03 35 | Sept.            | 8  | 12 52 | Sept.               | 16 | 17 20 |
| Sept.           | 23 | 19 55 | Sept.                | 30 | 11 12 | Oct.             | 8  | 04 55 | Oct.                | 16 | 08 59 |
| Oct.            | 23 | 05 10 | Oct.                 | 29 | 22 05 | Nov.             | 6  | 23 15 | Nov.                | 14 | 22 39 |
| Nov.            | 21 | 15 11 | Nov.                 | 28 | 12 59 | Dec.             | 6  | 18 15 | Dec.                | 14 | 10 14 |
| Dec.            | 21 | 02 08 | Dec.                 | 28 | 07 48 |                  |    |       |                     |    |       |

All times are G.M.T.

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## MONTHLY NOTES, 1976

### January

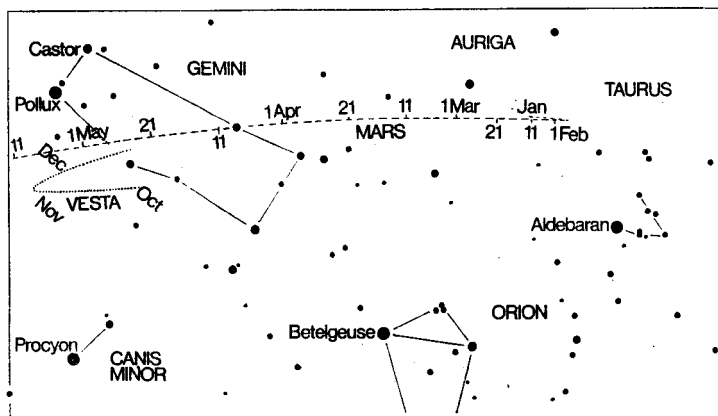
*New Moon:* 1 and 31 January    *Full Moon:* 17 January

**Earth** is at perihelion (nearest to the Sun) on 4 January at a distance of 91,400,000 miles (147,100,000 km).

**Mercury** is at greatest eastern elongation ( $19^\circ$ ) on 7 January, and the planet is bright enough for a few days before this date to be seen as an evening star, low in the south-west at about  $17^h$ . Mercury is in inferior conjunction on 23 January.

**Venus** will not be a very impressive object in 1976, but may be seen as a morning star throughout January. At the beginning of the month it rises in the south-east about three hours before sunrise, but this interval decreases during the month, the planet moving south and therefore rising later each morning. By the end of the month it is only visible for about two hours before sunrise. (Magnitude  $-3.5$ .)

**Mars** was at opposition in December last, and is still a brilliant object (magnitude  $-1.1$  to  $-0.2$ ) moving retrograde in Taurus. It will be seen in the south in the late evening, and sets in the north-west about an hour before sunrise. Mars reaches a stationary point on 20 January, some degrees north of Aldebaran and Orion.



*Mars, January-May, 1976*

**Jupiter** was at opposition last October and is still a brilliant evening star, setting about midnight in the west. The planet is moving direct in Pisces and is quite conspicuous (magnitude  $-2.1$  to  $-1.9$ ) among the faint stars in this part of the sky. A diagram of the path of Jupiter during the year is given with the November notes on page 100.

**Saturn** is at opposition on 20 January, and will be found in the south at midnight among the stars of Cancer (see diagram on page 62). Above it and to the west are the Twins, Castor and Pollux, but the planet is much brighter (magnitude  $-0.1$ ) than either of these stars. The distance of Saturn from the Earth at opposition is 752 million miles (1,210 million km), much the same as it was at the very favourable opposition of 1973, when the rings were open at their widest. The rings are now closing, and as a result, the planet is not quite as bright as it was at the last two oppositions. The south pole of Saturn is tilted towards the Earth, but the far side of the rings no longer appears clear of the body of the planet. The largest satellite, Titan, will be at extreme eastern elongation on 1 January, and is easily seen in a small telescope.

# THE CANALS OF MARS: END OF A LEGEND

Though Mars passed opposition on 15 December 1975, and is now receding from the Earth, it is still a brilliant red object – it is, in fact, brighter than any star apart from Sirius. For the rest of 1976 it will be relatively remote, but it will be very much ‘in the news’, since a probe is scheduled to land upon it and tell us, once and for all, whether there is any life there. Meantime, one problem has at least been solved. There are no artificial canals, and the sophisticated network of channels drawn and described by men such as Percival Lowell does not exist.

The story of the canals began during the last century, but not much was heard of it until 1877, when G. V. Schiaparelli, at Milan, used his excellent refracting telescope to draw a new map of Mars (and, incidentally, to name the main features). Crossing the red ‘deserts’ Schiaparelli saw some strange dark lines, which seemed to him to make up a geometrical pattern. He called them *canali*, which is Italian for ‘channels’; inevitably, the word was translated as ‘canals’ – and canals they have remained.

For some years nobody else could record them, but then other observers started to see them. Canals became all the rage, and maps of Mars looked very curious indeed. Percival Lowell, who founded the Lowell Observatory at Flagstaff in Arizona mainly to study them, was convinced of their artificial nature, and he was absolutely certain that Mars must be the home of an advanced civilization which had long since abandoned what he called ‘puerile’ pastimes such as warfare. To Lowell, the canals existed to draw water from the polar ice-caps through to the equatorial regions; the ‘oases’ where the canals crossed each other were centres of population; when one canal proved inadequate to cope with the water supply, a second one was opened – so that a formerly single canal might abruptly become twins. This was what Lowell called ‘gemination’.

His papers and books, published between 1895 and his death in 1916, caused immense interest and immense controversy. He met with strong support, but he also met with fierce opposition, and it is probably true to say that the anti-canal party was the

more numerous of the two. Lowell himself was well aware that a broad sheet of open water would be subject to strong evaporation, and he believed a canal to be narrow (possibly piped), flanked to either side by irrigated land. Others were not so cautious. For instance, C. E. Housden, in 1914, wrote a book called *The Riddle of Mars* in which he described the Martian pumping stations in considerable detail!

One disturbing fact, from the pro-canal party's point of view, was that not everybody could see them. Lowell used his excellent 24-inch refractor, but E. M. Antoniadi, working with an even larger telescope – the 33-inch refractor at Meudon, near Paris – was emphatic that no Lowell-type features existed. He regarded them as being due to tricks of the eye, caused usually by slight differences in tone between two adjacent areas.

It also became clear that the ice-caps at the poles could not be thick, and were in no way comparable with the great sheets covering our Greenland or Antarctica. Spectroscopic analysis showed the Martian atmosphere to be very dry as well as very thin, and by the outbreak of the last war the caps were relegated to very minor coatings – less than a foot deep, and probably only an inch or two. They could not, therefore, provide enough water to fill even one major canal, to say nothing of the hundreds drawn by Lowell and his supporters. The theory of artificial waterways was more or less abandoned; but the mystery of the canals themselves remained.

Then, in the 1960s, came the probes – Mariner 4 in 1965, Mariners 6 and 7 in 1969. For the first time the great craters were revealed; and then, with Mariner 9, the volcanoes and valleys. All our ideas about Mars were drastically revised. The atmosphere proved to be even more tenuous than had been thought, and to be made up chiefly of carbon dioxide; the polar caps, too, were generally believed to be solid carbon dioxide, with only a small amount of ordinary ice. This put paid to any suggestion of water-filled canals, piped or otherwise.

The canals, too, were abandoned – not without reluctance! On Mars there are various linear features; there are the valleys,

and there are mountains; there are also chains of craters – but there is nothing remotely like the straight, regular canals shown on Lowell's maps. The brilliant-brained Martians have stepped out of science and into the story-books; the only question now is whether there is any life there at all. Most astronomers doubt it, though to say baldly that Mars is sterile would be premature. We must await the results of Viking.

The canals, then, do not exist, in the form which Lowell and others believed less than seventy years ago. When straining to catch detail at the very limit of visibility, it is only too easy for the human eye to be deceived. Yet even though his theories of Mars were wrong, Lowell must still be regarded as one of the great astronomers of the past hundred years. He carried out much valuable work; in particular it was his calculations which led to the tracking-down of the ninth planet, Pluto. It would be quite unfair to link him only with the mythical canals of Mars.

## February

*Full Moon:* 15 February    *New Moon:* 29 February

**Mercury** is at greatest western elongation ( $26^\circ$ ) on 16 February. It is then a morning star, but is very low in the south-east at sunrise and not very bright. The planet Venus is in the same part of the sky, but is farther to the east, higher in the sky, and several magnitudes brighter.

**Venus** is a morning star, but rises in the south-east only about an hour before the Sun at the end of the month. Venus reaches its most southerly point at the beginning of February and then begins to move north again. (Magnitude  $-3.5$  to  $-3.4$ .)

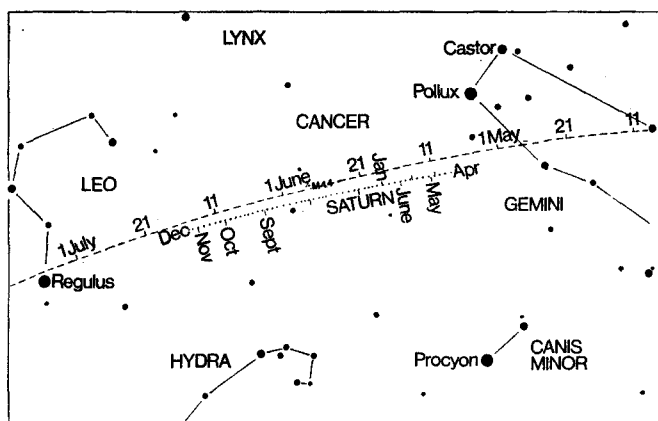
**Mars** is an evening star moving direct in Taurus. It is visible for most of the night, setting north of west about three hours before sunrise. The planet is now fading rapidly (magnitude  $-0.2$  to  $+0.5$ ) as its distance from the Earth increases – by the end of the month it is more than 100 million miles from us, and more than two magnitudes fainter than it was at opposition.

**Jupiter** is an evening star to be seen in the south at sunset and setting in the west before midnight. It is to be seen in the eastern part of Pisces, and is a conspicuous object in this part of the sky where there are few bright stars (magnitude  $-1.9$  to  $-1.7$ ).

**Saturn** is still a very bright object, visible for most of the night but setting north of west about an hour before sunrise at the end of February. Its retrograde motion in Cancer carries it back across the border into Gemini in mid-February, and it will then be seen

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below and in a line with the Twins, Castor and Pollux. (Magnitude  $-0.1$  to  $+0.1$ .)



*Saturn, 1976*

### LEAP YEAR

This year Full Moon falls on 29 February. It could not have done so in 1975, as there was then no 29 February. The second month in our calendar is also the shortest; but this year it has one more day than usual. 1976 is a Leap Year.

The reason for this is that the Earth goes round the Sun not in 365 days, but in  $365\frac{1}{4}$ . Obviously the civil calendar must be made convenient; but if nothing were done, the quarter-days would add up to such an extent that we would find Christmas falling in the northern summer. Therefore, one year in every four has an extra day, which more or less compensates; and it is only fair to tack this extra day on to the shortest month.

To decide whether a year is Leap Year or not, simply divide by 4. If there is no remainder, we have a Leap Year. Thus 1976 divided by 4 comes to 494 exactly. 1977 divided by 4 comes to 494 with a remainder of 1 – and so 1977 is not a Leap Year.

The only exception is with regard to the 'century years' (1800,

1900, 2000, etc), where the division has to be by 400. Thus 1900 was not a Leap Year, but 2000 will be.

Even now the calendar is not absolutely accurate; but the errors are so small that they will take many centuries to build up to anything noticeable, and for all practical purposes we can ignore them.

#### STARS OF THE 'FIRST MAGNITUDE'

Two of the most famous stars in the northern sky are the Twins, Castor and Pollux. They lie side by side, not far from Orion, and are easy to find. They are not really associated (Castor is the more distant of the two), and they are not equal; Pollux is the brighter. Its magnitude is 1.16, whereas that of Castor is 1.58. So far as Castor is concerned, this is the combined magnitude of two components which are so close together that to the naked eye they appear as one; for the moment, let us regard Castor as a single star.

Conventionally, stars of above magnitude 1.5 are ranked as being of the 'first magnitude', so that Pollux merits inclusion in the list while Castor does not. There is a similar case in the far south of the sky. In the Southern Cross, Beta Crucis (1.31) is regarded as being of the first magnitude, while Gamma (1.61) is not – yet the difference between the two is slight.

The whole nomenclature is somewhat arbitrary, and it may be of interest to give two lists; one made up of stars conventionally called 'first magnitude', and the other consisting of stars which are below the unofficial limit and yet are brighter than magnitude 2.0. The lists are on the next page.

A few of these stars, such as Polaris, are slightly variable (Polaris is a Cepheid with a very small range), but the only one to show marked fluctuations is Betelgeux, the red star in Orion's 'shoulder', which can sometimes outshine Procyon very obviously, though at other times it is more comparable with Aldebaran. During the 1830s, when Sir John Herschel was observing the skies from the Cape of Good Hope, he once noted that Betelgeux was very little different from Rigel.

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| <i>First Magnitude</i>            |               | <i>Between Magnitude 1·5 and 2·0</i> |      |
|-----------------------------------|---------------|--------------------------------------|------|
| Sirius (Alpha Canis Majoris)      | —1·43         | Castor (Alpha Geminorum)             | 1·58 |
| Canopus (Alpha Carinæ)            | —0·73         | Gamma Crucis                         | 1·61 |
| Alpha Centauri                    | —0·27         | Adhara (Epsilon Canis Majoris)       | 1·63 |
| Arcturus (Alpha Boötis)           | —0·06         | Alioth (Epsilon Ursæ Majoris)        | 1·68 |
| Vega (Alpha Lyræ)                 | 0·04          | Bellatrix (Gamma Orionis)            | 1·70 |
| Capella (Alpha Aurigæ)            | 0·09          | Shaula (Lambda Scorpii)              | 1·71 |
| Rigel (Beta Orionis)              | 0·15          | Avior (Epsilon Carinæ)               | 1·74 |
| Procyon (Alpha Canis Minoris)     | 0·37          | Alnilam (Epsilon Orionis)            | 1·75 |
| Achernar (Alpha Eridani)          | 0·58          | Al Nath (Beta Tauri)                 | 1·78 |
| Betelgeux (Alpha Orionis)         |               | Miaplacidus (Beta Carinæ)            | 1·80 |
|                                   | var., 0·2–0·9 | Alpha Trianguli Australe             | 1·88 |
| Agema (Beta Centauri)             | 0·66          | Mirphak (Alpha Persei)               | 1·90 |
| Altair (Alpha Aquilæ)             | 0·80          | Alkaid (Eta Ursæ Majoris)            | 1·91 |
| Aldebaran (Alpha Tauri)           | 0·85          | Alnitak (Zeta Orionis)               | 1·91 |
| Acrux (Alpha Crucis)              | 0·87          | Gamma Velorum                        | 1·92 |
| Antares (Alpha Scorpii)           | 0·98          | Alhena (Gamma Geminorum)             | 1·93 |
| Spica (Alpha Virginis)            | 1·00          | Dubhe (Alpha Ursæ Majoris)           | 1·95 |
| Fomalhaut (Alpha Piscis Austrini) | 1·16          | Kaus Australis (Epsilon Sagittarii)  | 1·95 |
| Pollux (Beta Geminorum)           | 1·16          | Wezea (Delta Canis Majoris)          | 1·98 |
| Deneb (Alpha Cygni)               | 1·25          | Mirzam (Beta Canis Majoris)          | 1·99 |
| Beta Crucis                       | 1·31          | Polaris (Alpha Ursæ Minoris)         | 1·99 |
| Regulus (Alpha Leonis)            | 1·36          |                                      |      |

In those days there was another first-magnitude star: Eta Argûs, now, since the splitting-up of the vast constellation of Argo Navis, known as Eta Carinæ. (Carina is the Keel of the old Ship; Canopus is its leader.) Eta Carinæ was then one of the most splendid stars in the sky, and at times outshone all others apart from Sirius; but after the middle of the last century it faded, and ever since about 1886 it has been invisible to the naked eye. Whether it will again rise to eminence remains to be seen; it is in every way an exceptional object.

## March

*Summer Time* in Great Britain and Northern Ireland commences on 21 March.

*Full Moon:* 16 March    *New Moon:* 30 March

*Equinox:* 20 March

**Mercury** is not likely to be seen during the month. At the beginning of March it is too low in the sky to be seen as a morning star at sunrise, while at the end of the month it is approaching superior conjunction.

**Venus** is a morning star, but rises less than an hour before the Sun at the beginning of the month. It is now moving round to the far side of its orbit, and later in the month is likely to be too close to the Sun to be seen. This state of affairs will continue until the autumn, when Venus begins to appear as an evening star.

**Mars** will be seen in the south at sunset. It is continuing to fade (magnitude  $+0.5$  to  $+1.1$ ) and is moving direct in Taurus. In mid-March it passes into Gemini and by the end of the month will be seen to the north of the right-hand side of the figure of Gemini. As the constellation sets in the north-west in the early morning hours, Mars will be seen to the right of the feet of the upright figure. (Star Charts 4L and 5L.)

**Jupiter** is a brilliant evening star (magnitude  $-1.7$  to  $-1.6$ ) setting in the west in mid-evening. The planet moves into Aries

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and at the end of the month will be seen to the south of the bright stars Alpha (Hamal) and Beta Arietis.

**Saturn** reaches a stationary point on 27 March on the eastern borders of Gemini, some degrees south of the Twins, Castor and Pollux. At the end of the month, Saturn sets about two hours before sunrise.

**Pluto** is at opposition on 30 March in Virgo, near the star Epsilon Virginis (see diagram in July notes on page 83). The distance of Pluto at this opposition is 2,759 million miles (4,440 million km) and it is too faint to be seen with small telescopes (magnitude +14).

**The Full Moon** of 16 March will occur at perigee, the nearest point to the Earth. The distance of the Moon will then be 222,200 miles from the Earth, and it should be possible to devise some method of demonstrating that this Full Moon is much nearer – and therefore larger – than the Full Moon of November, which will be at apogee, more than 30,000 miles farther away.

### **JUNO: ASTEROID No. 3**

The third minor planet or asteroid in order of discovery, Juno, comes to opposition on 1 March. It is then near the border between Sextans and Leo, and is, of course, too faint to be seen with the naked eye; only one asteroid – Vesta – is ever visible without optical aid.

The story of the asteroids really began in 1801, with the discovery of Ceres. The astronomer responsible was Piazzi, at the Sicilian observatory of Palermo; at the time he was not looking for new planets, so that the discovery was accidental – even though Piazzi must be given full credit for realizing that he had found an object which moved, and which could not, therefore, be a star. At that time the 'celestial police' were starting their patrols, with the set intention of hunting for a new planet moving round the Sun

between the orbits of Mars and Jupiter. Piazzi was not an original member of the team (though he joined later) but a certain Dr Olbers, a German amateur astronomer, was in their ranks; and in March 1802 he discovered the second asteroid, Pallas.

Juno followed on 1 September 1804. The discoverer was Karl Ludwig Harding, who had been born at Lauenberg in 1765, and educated for the Lutheran ministry. He acted as tutor to the sons of Johan Hieronymus Schröter, chief magistrate of Lilienthal, who was one of the great pioneer observers of the Moon and planets, and secretary of the 'celestial police'. Through Schröter, Karl Harding became interested in astronomy. He was appointed assistant to Schröter at the private Lilienthal observatory, and it was here that he made the discovery of Juno. He stayed at Lilienthal for some time, but was appointed to a chair of astronomy at Göttingen in 1813, and published an excellent star atlas nine years later; he also discovered eight new nebulae, and remained astronomically active until his death in March 1834.

Though Juno is Asteroid No. 3, it is not third in order of size; several others are larger – such as No. 10, Hygeia, found by De Gasparis from Naples in 1849. Until recently, Juno's diameter was given as 150 miles, as against 427 for Ceres, 280 for Pallas, 370 for Vesta and 220 for Hygeia. However, recent studies by D. A. Allen, carried out by infra-red techniques, have shown that the asteroids are larger than had been thought; the diameter of Ceres is now thought to be between 600 and 700 miles, and the other members of the swarm are larger by the same proportion. Therefore, the diameter of Juno is probably around 200 miles – perhaps even more. Its revolution period is 4.36 years, and its mean distance from the Sun is 247,800,000 miles.

Vesta, Asteroid No. 4, was discovered in 1807, again by the patient Dr Olbers, but then there was a long hiatus before the fifth member of the swarm came to light; this was Astræa, found in 1845 by Hencke, a German postmaster who took up astronomy as a hobby and concentrated upon asteroid-hunting. It may be of interest to give the names and discoverers of the asteroids found before the end of 1855. They are:

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| <i>Name</i>   | <i>Discoverer</i> | <i>Name</i>   | <i>Discoverer</i> |
|---------------|-------------------|---------------|-------------------|
| 1 Ceres       | Piazzi, 1801      | 20 Massilia   | De Gasparis, 1852 |
| 3 Pallas      | Olbers, 1802      | 21 Lutetia    | Goldschmidt, 1852 |
| 2 Juno        | Harding, 1804     | 22 Calliope   | Hind, 1852        |
| 4 Vesta       | Olbers, 1807      | 23 Thalia     | Hind, 1852        |
| 5 Astræa      | Hencke, 1845      | 24 Themis     | De Gasparis, 1853 |
| 6 Hebe        | Hencke, 1847      | 25 Phoebe     | Chacornac, 1853   |
| 7 Iris        | Hind, 1847        | 26 Proserpine | Luther, 1853      |
| 8 Flora       | Hind, 1847        | 27 Euterpe    | Hind, 1853        |
| 9 Metis       | Graham, 1848      | 28 Bellona    | Luther, 1854      |
| 10 Hygeia     | De Gasparis, 1849 | 29 Amphitrite | Marth, 1854       |
| 11 Parthenope | De Gasparis, 1850 | 30 Urania     | Hind, 1854        |
| 12 Victoria   | Hind, 1850        | 31 Euphrosyne | Ferguson, 1854    |
| 13 Egeria     | De Gasparis, 1850 | 32 Pomona     | Goldschmidt, 1854 |
| 14 Irene      | Hind, 1851        | 33 Polyhymnia | Chacornac, 1854   |
| 15 Eunomia    | De Gasparis, 1851 | 34 Circe      | Chacornac, 1855   |
| 16 Psyche     | De Gasparis, 1852 | 35 Leucothea  | Luther, 1855      |
| 17 Thetis     | Luther, 1852      | 36 Atalanta   | Goldschmidt, 1855 |
| 18 Melpomene  | Hind, 1852        | 37 Fides      | Luther, 1855      |
| 19 Fortuna    | Hind, 1852        |               |                   |

There followed five asteroid discoveries in 1856, nine in 1857, five in 1858 and only one in 1859 – after which the list of known members of the swarm grew with remarkable speed. Eventually the supply of romantic mythological names gave out, and recently-discovered asteroids have names of very different kind. One of them is even named after a computer!

## PLUTO

Pluto, the ninth planet, is also at opposition this month, but it is much fainter than Juno, and cannot be seen with a small telescope. Even with giant instruments, it looks like nothing more than a dim star. Its diameter is still rather uncertain, but it seems to be considerably smaller than the Earth, and probably smaller than Mars – though this is still much larger than any of the asteroids. There have been suggestions that Pluto itself may be merely the brightest member of a ring of remote trans-Neptunian asteroids, but this idea seems to have fallen into disfavour. It is possible that Pluto may be a former satellite of Neptune, which broke free for some reason unknown; certainly it is comparable in size with Triton, the larger of Neptune's two remaining satellites.

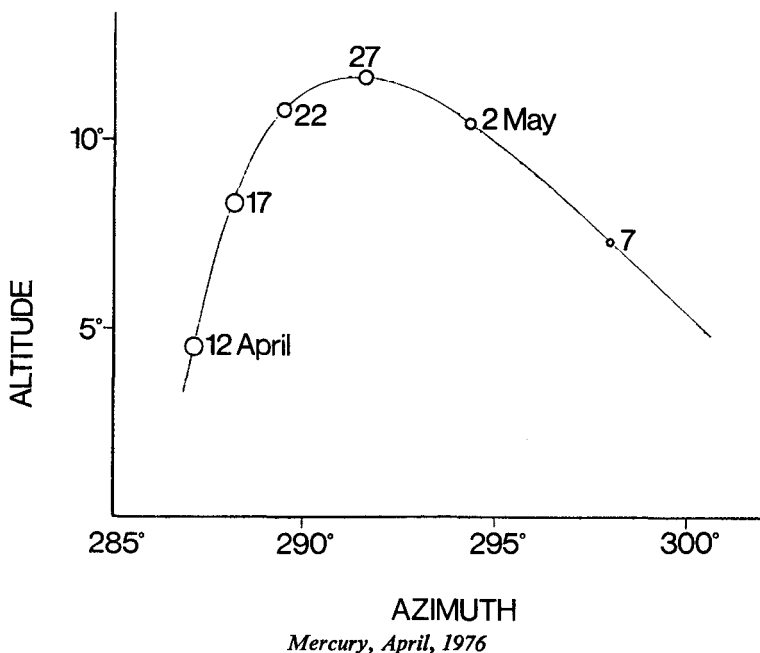
## MONTHLY NOTES · MARCH

However, there is no proof. Pluto has set astronomers problem after problem since its discovery by Clyde Tombaugh in 1930, and even now we are uncertain of its true nature.

## April

*Full Moon:* 14 April    *New Moon:* 29 April

**Mercury** is in superior conjunction on 1 April and at greatest eastern elongation on 28 April ( $21^\circ$ ). This will be a favourable opportunity to see this elusive planet as an evening star. The diagram below shows the changes in altitude and azimuth (true bearing from the north through east, south and west) of Mercury on successive evenings when the Sun is six degrees below the



horizon; this is about 40 minutes after sunset at this time of year. The changes in brightness are roughly indicated by the size of the circles, and it will be seen that Mercury is brightest *before* the date of eastern elongation.

**Venus** is still theoretically a morning star, but is too close to the Sun to be seen.

**Mars** continues to move direct through the constellation of Gemini. By the end of April it will be seen to the south of the Twins, and sets in the north-west about an hour after midnight (magnitude +1.1 to +1.5).

**Jupiter** is in conjunction on 27 April and is not likely to be seen during the month. After conjunction it reappears quite rapidly as a morning star.

**Saturn** will be seen in the south at sunset and sets in the north-west in the early morning hours. The planet is now moving direct on the borders of Gemini and Cancer (magnitude +0.3 to +0.4).

**Uranus** is at opposition on 25 April on the borders of Virgo and Libra. The magnitude at opposition is +5.7 and it should be just visible to the naked eye. It will be more easily found with a small telescope, when it appears as a greenish disk. At opposition Uranus is 1,630 million miles (2,600 million km) from the Earth. The path of Uranus during the year is shown in the diagram on page 76.

**An annular eclipse of the Sun** on 29 April may be seen in the British Isles as a partial eclipse beginning at 9<sup>h</sup> G.M.T. About forty per cent of the Sun's disk will be covered by the Moon at mid-eclipse at about 10<sup>h</sup> 13<sup>m</sup>. For further details see page 109.

#### THIS MONTH'S ECLIPSE OF THE SUN

There can be nothing in Nature to equal the glory of a total

eclipse of the Sun, when, for a few seconds or a few minutes, the chromosphere, the prominences and the corona shine out. This month's eclipse, however, is not total anywhere, because the Moon is not far from apogee, and appears smaller than the Sun in the sky. The result is that a ring of sunlight is left showing around the lunar disk, and we have an annular eclipse (Latin *annulus*, a ring). Details are given on page 109. From Great Britain the eclipse will be partial.

For seeing the Sun's atmosphere with the naked eye, an eclipse must be total; the slightest sliver of the brilliant disk is sufficient to hide even the chromosphere. This means that partial and annular eclipses are relatively unspectacular. All the same, they are worth looking at.

Great care is needed. To turn a telescope or binoculars towards the Sun, and look direct, is certain to cause permanent blindness, and one should never trust the dark eyepiece filters which – so some telescope suppliers say – can be fitted over the telescope eyepiece to give protection. The only sensible method is to project the Sun's image on to a screen held behind the telescope. Neither is it wise to stare straight at the Sun even without a telescope, since a probable result will be 'spots before the eyes', and there is a chance of real damage. During the last partial eclipse visible in England, quite a number of people had to be treated in hospital for eye damage. Remember that a half-eclipsed Sun is just as dangerous as a Sun which is fully visible.

#### MERCURY: THE ELUSIVE PLANET

Mercury is the least obtrusive of the planets known in ancient times. It is bright, but it can never be seen against a dark background, and there must be many people who have never seen it at all; city-dwellers are at a hopeless disadvantage, since a clear horizon is essential. (On no account sweep round with binoculars or a telescope, looking for Mercury, until after the Sun has set.)

There is a story that the great astronomer Copernicus, whose book *De Revolutionibus* revived the theory that the Earth goes round the Sun instead of *vice versa*, never managed to see Mercury

at all, because of mists rising from the river Vistula which flows through his home town of Toruń. Yet this story seems implausible. Copernicus spent some time in Italy, where the skies are clear, and from modern Toruń the horizon is quite transparent enough for Mercury to be seen. Moreover, Copernicus spent his later life at Frombork, which he himself described as 'the remotest corner of the earth', and where there were certainly no brilliant lights. All in all, the legend seems to be of the 'Canute-and-the-waves' type.

Yet even though Mercury can be found easily enough, there is little point in trying to study its surface markings when the planet is visible with the naked eye, because it is bound to be low down. The first astronomer to attempt a really serious study of Mercury was Schiaparelli, almost a century ago. He preferred to observe when the planet was high in the sky; this meant, of course, that the Sun was also high, and the planet could not be located at all without a telescope equipped with accurate setting circles.

Schiaparelli drew a map of Mercury, showing some dark regions and brighter patches. Other observers followed him, and in the 1930s came the map by E. M. Antoniadi, who used the 33-inch Meudon refractor for his main work. Antoniadi drew up a more detailed map, and gave names to the main features.

This was about as much as was known until 1974, when Mariner 10 made its first passes of the planet and sent back pictures showing that the surface is cratered. By now, fairly good maps of most of the surface have been compiled, and the similarity with the Moon is striking.

How do the Mariner results compare with the old charts by Schiaparelli, Antoniadi, and others? The answer must, unfortunately, be: 'Not well'. So far as Mars was concerned, Antoniadi has been proved to be as accurate as anyone could hope; but his chart of Mercury does not agree with the new results – and he was almost certainly wrong, too, in believing that Mercury's surface features could sometimes be hidden by local obscurations on the planet itself. The Mercurian atmosphere is negligible, and it is hard to credit that there could be any 'clouds' major enough to be seen from Earth.

All this underlines, once again, how difficult an object Mercury is to the Earth-based observer. Telescopes of moderate size can do no more than show the characteristic phase. Yet this alone is worth while, and during the latter part of this month people who live well away from towns should have little trouble in locating this quick-moving, elusive planet which was so aptly named in honour of the Messenger of the Gods.

#### CORVUS

Look rather low in the south during April evenings, and you will find a quadrilateral of reasonably bright stars, standing out mainly because they lie in a barren area (both Spica and Regulus are some distance away). This pattern makes up Corvus, the Crow. The four leading stars are all of around the third magnitude.

Corvus contains little of real interest, but it was one of the original 48 constellations listed by Ptolemy, and there is a legend attached to it. It is said that the crow was sent by the god Apollo to keep watch on Coronis, mother of the great doctor Æsculapius, with whom Apollo had fallen in love. Though the crow's report was hardly favourable to Coronis, Apollo rewarded the bird with a place in the sky!

## May

*Full Moon:* 13 May    *New Moon:* 29 May

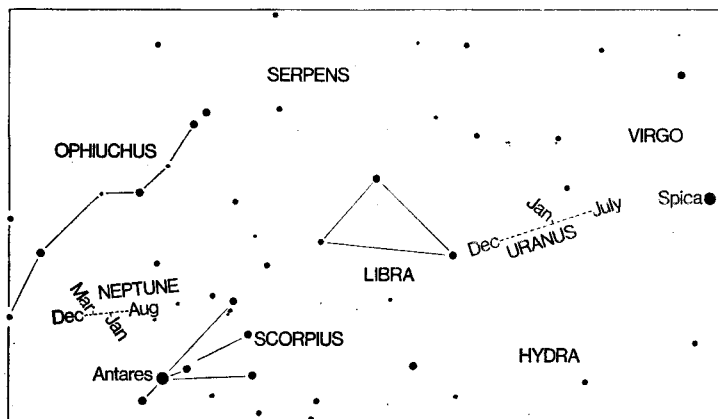
**Mercury** is an evening star for the first few days of the month (see April notes), but moves rapidly towards inferior conjunction on 20 May.

**Venus** is still a morning star, but is only a few degrees from the Sun and is not likely to be seen in the bright dawn sky.

**Mars** is an evening star, but now sets at midnight. It is moving direct in Gemini, and on 5 May it will be  $5^{\circ}$  south of Pollux, and passes rather more than a degree north of Saturn on the night of 11 May. In mid-May it passes into Cancer, and will then be seen in a line with the Twins, Castor (magnitude  $+1.6$ ) and Pollux (magnitude  $+1.2$ ). Magnitude of Mars  $+1.5$  to  $+1.7$ . The apparent motion of Mars is quite rapid, and by the end of May it will be near the interesting star-cluster Præsepe (the 'Beehive') M44.

**Jupiter** is now a morning star but is too close to the Sun to be seen until the end of the month, when it rises about an hour before sunrise. It is moving direct in Aries towards the Pleiades, with the figure of Cetus below it (magnitude  $-1.6$ ).

**Saturn** may be seen for most of the evening, but sets at midnight by the end of the month. The planet moves from Gemini into Cancer at the beginning of May, and will be seen south of Mars on the evening of 11 May. Saturn is then much the brighter of the two (magnitude  $+0.4$ ).

*Uranus and Neptune, 1976*

A **partial eclipse of the Moon** occurs on the evening of 13 May, when the Earth's shadow will cover about 13 per cent of the Moon's face. In the British Isles the Moon will rise eclipsed, the maximum being reached at 19<sup>h</sup> 54<sup>m</sup>. Further details are given on page 109.

#### OCCULTATIONS OF PLANETS BY THE MOON

As the Moon passes across the sky, it frequently hides or occults stars. It is true that stellar occultations are not quite so common as might be thought from a casual glance up into a starlit sky – the Moon, after all, looks small (much smaller than is generally believed; artists' impressions are nearly always very wide of the mark) and the number of stars visible with the naked eye is also much less than some people believe. Most stellar occultations have to be observed with the aid of a telescope. As will be seen from the notes on page 111, only four first-magnitude stars are sufficiently close to the ecliptic to be occulted by the Moon.

Stellar occultations are useful, because the positions of the stars are known more precisely than the movements of the Moon. If an occultation is timed, it gives the exact position of the Moon at that particular moment. Occultation work is a favourite amateur pastime – and a very valuable one; this is still true today, even

though it must be admitted that modern techniques have made occultation timings less vital than they were twenty or thirty years ago.

Of course, the planets can also be hidden by the Moon. This month it is Jupiter's turn. Details are given on page 111; unfortunately the observation will not be easy, as the Moon is so close to new.

Planetary occultations are always worth studying, mainly to see whether any unusual phenomena occur. We know that the Moon's atmosphere is negligible – which is why an occulted star seems to snap out instantaneously (though there are occasionally exceptions. A star appears as a point of light. A planet, however, shows a disk, and so it takes some time to pass behind the Moon or to emerge at the end of the occultation.

W. H. Pickering, a famous American astronomer (he died in 1940), recorded dark lines, parallel to the Moon's limb, across the disk of a planet which was in the process of being occulted. Pickering attributed this to a lunar atmosphere; and this was one of his main reasons for thinking that the Moon's atmospheric mantle must be of appreciable density. Today, this explanation can no longer be accepted, and we have to find some other reason for the dark bands, which are of course visible for only very short periods – it does not take a planet long to pass behind the Moon.

The reality of the phenomena is very much in doubt. Many observers have watched planetary occultations for years without seeing anything unusual; and certainly it seems that 'Pickering bands' are the exception rather than the rule. Yet reliable observers have seen them, and they cannot be dismissed out of hand.

There seems no chance that the bands – if they exist at all – can be due to anything directly connected with the Moon or the planet. They must be optical effects, though the cause is still not definitely known. More observations are needed, and amateurs can play a useful role, though a fairly large telescope is necessary. It is a pity that planetary occultations are so uncommon.

#### THE BRIGHTEST STARS

There can be no doubt that Sirius is the brightest star in the

sky; that Canopus, in the far south, comes next; and that No. 3 in the list is another southern star, Alpha Centauri (actually, Alpha is a binary; with the naked eye we see it as one object). Next in order come four stars which are almost equal. Arcturus, in Boötes, is splendidly on view during May evenings; find it by following round the 'tail' of the Great Bear, and note its lovely orange colour. Vega and Capella lie on opposite sides of the Pole Star; the fourth contender, Rigel in Orion, will return to the night sky at the beginning of autumn.

It is interesting to look at some of the values given for the magnitudes of these four stars. E. C. Pickering, in his *Revised Harvard Photometry*, differed from Pritchard's Oxford value; we also have the magnitudes given in the much more modern *Atlas Cæli*, the magnitudes given in the 1973 *Handbook* of the British Astronomical Association, and the most modern photoelectric values, as follows:

|          | <i>Pickering</i> | <i>Pritchard</i> | <i>Atlas Cæli</i> | <i>BAAH</i> | <i>Latest value</i> |
|----------|------------------|------------------|-------------------|-------------|---------------------|
| Arcturus | 0.0              | 0.3              | 0.24              | -0.06       | -0.06               |
| Vega     | 0.2              | 0.8              | 0.14              | 0.04        | 0.04                |
| Capella  | 0.2              | 0.1              | 0.21              | 0.09        | 0.05                |
| Rigel    | 0.3              | 1.0 (!)          | 0.34              | 0.08        | 0.15                |

It seems, then, that Arcturus is slightly the most brilliant of the four, but there is little difference between them. Casual comparisons are not easy, because altitude is all-important, and moreover, the colours are not the same; Arcturus is orange, Capella yellowish, Vega bluish, and Rigel pure white. Of the quartet, Rigel is much the most remote and luminous.

## June

*Full Moon:* 12 June    *New Moon:* 27 June

*Solstice:* 21 June

**Mercury** is at greatest western elongation ( $23^\circ$ ) on 15 June. It is then a morning star, but is not very bright and will be difficult to see in the dawn sky.

**Venus** is in superior conjunction on 18 June and will not be visible during the month.

**Mars** continues to be visible after sunset, but by the end of the month it sets in the west in the late evening. The planet is not very bright (magnitude  $+1.7$  to  $+1.9$ ), but should be easy to find in a rather barren part of the sky. Mars passes through Cancer into Leo and by the end of the month will be seen a few degrees west of the star Regulus (magnitude  $+1.3$ ).

**Jupiter** rises an hour or two before the Sun, and although the sky is never really dark at this time of year, Jupiter will be quite a bright object in the eastern sky before dawn (magnitude  $-1.6$  to  $-1.7$ ). The planet is still moving direct in Aries.

**Saturn** sets in the late evening in Cancer but is now moving rapidly towards conjunction with the Sun.

**Neptune** is in opposition on 3 June and is then at a distance of 2,720 million miles (4,380 million km) from the Earth. The planet is actually in the constellation Ophiuchus, but is near Antares and

the other bright stars of Scorpius (see diagram on page 76). Neptune is not visible to the naked eye (its magnitude is  $+7.7$ ), but may be found with binoculars or a small telescope.

### THE STAR-CLOUDS OF SAGITTARIUS

To British and North American observers, June evenings provide the best times for seeing the lovely star-clouds of Sagittarius, the Archer. Not only are they beautiful, but they are also significant. When we look at them, we are looking in the direction of the very centre of the Galaxy.

Sagittarius, the Archer, is a bright constellation. Unlike its neighbour, the Scorpion, it contains no first-magnitude star; the two leaders are Epsilon or Kaus Australis (magnitude 1.8) and Sigma or Nunki (2.1). Neither is there any really distinctive shape. The outline is nothing like that of an archer; some people have compared it with a teapot. Deneb in Cygnus, Altair in Aquila, and Sagittarius lie in more or less a straight line, with Altair in the middle; this is probably the best way to locate the constellation.

There are plenty of interesting telescopic objects, including the Omega or Horseshoe Nebula (Messier 17) in the northern part of the constellation, not far from Gamma Scuti; the Lagoon Nebula (Messier 8) near Mu Sagittarii, and the bright globular cluster Messier 22, between Mu and Nunki. Unfortunately, Sagittarius lies well to the south of the celestial equator – it is the southernmost of the Zodiacal constellations – and so it is never seen at its best from latitudes such as those of London or New York. Of course, this reacts to the advantages of Australians and South Africans, who are able to see both Sagittarius and Scorpio in their true glory.

The star-clouds of Sagittarius are rich indeed, and the observer with a small telescope will find endless enjoyment in sweeping round them. This is, in fact, the richest part of the Milky Way. For centuries now we have known that the Galaxy is a flattened system, and it has been found that the Sun lies not far from the main plane, at a distance of about 32,000 light-years from the galactic centre. The whole system is rotating, and the Sun takes

some 225,000,000 years to complete one journey. The Coal Forest period on Earth took place only one 'cosmic year' ago!

The real galactic centre is hidden, simply because there is too much 'dust' in the way, and this dust blocks out the light-waves as effectively as a thick fog will blot out a landscape. However, radio waves are not blocked; and they were first detected in 1931 by Karl Jansky, a Czech-American who was employed by the Bell Telephone Laboratory.

Jansky was particularly interested in problems of 'static', and he had built a strange-looking aerial which was nicknamed the Merry-go-Round. He picked up plenty of static, but he also found a weak, persistent hiss which seemed to come from the sky. After some weeks' work, he managed to identify the source. The radio noise came from the Sagittarius star-clouds of the Milky Way. This was the beginning of the science of radio astronomy, which has by now become so vital a part of research. It is ironical that Jansky himself never followed up his great discovery as enthusiastically as he might have been expected to do, and it was only after the war that professional radio astronomy began.

#### NEPTUNE AND THE CELESTIAL POLICE

Neptune, at opposition this month, is of above the eighth magnitude, and so is easily visible in binoculars; a modest telescope will suffice to show that it is not a star, since it presents a definite, though small, disk. (Its maximum angular diameter is 2.2 seconds of arc.) The story of its discovery was told in the 1975 *Yearbook* (page 79) and there is no need to repeat it here, except to say that Neptune was tracked down as a result of mathematical studies of the perturbations of Uranus. The discovery was made in 1846.

There is, however, one interesting problem here. Why was Neptune not discovered earlier? John Couch Adams had calculated its position, and was (justifiably) confident; all he had to do was to take a pair of binoculars and look for a starlike object which shifted slowly from night to night. Even earlier, there had been the 'celestial police' who had deliberately set out to locate new planets.

It is true that the 'police' were searching for a planet between the paths of Mars and Jupiter, and Neptune, which is so much more remote, travels more slowly among the stars. Still, its motion is perceptible – and it is brighter than most of the asteroids. Its average magnitude is 7.7; and of the minor planet swarm only Vesta and Ceres are consistently brighter than this. It would have been fascinating if the 'police' had located Neptune, a distant giant, instead of the small trans-Martian world which they expected; but in retrospect it is not easy to see how they overlooked it, particularly since, like the other principal planets, it keeps strictly within the Zodiac.

For a few years around 1989 Neptune will again be the outermost member of the planetary family. Pluto, at perihelion, is closer-in; but the orbit of Pluto is inclined at the comparatively high angle of 17 degrees, and there is no chance of a collision between Pluto and Neptune.

## July

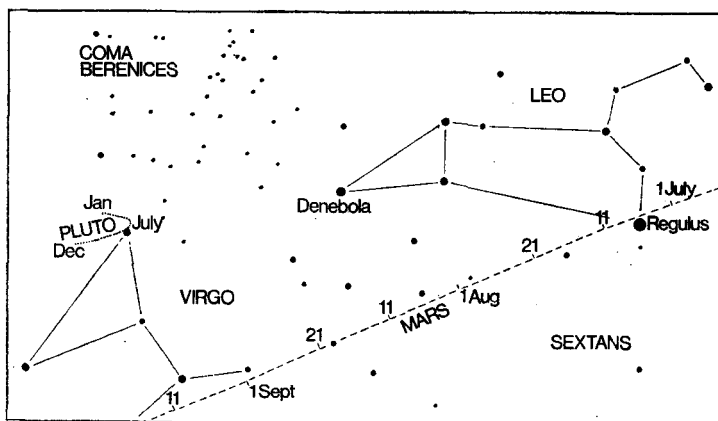
*Full Moon:* 11 July    *New Moon:* 27 July

**Earth** is at aphelion (farthest from the Sun) on 3 July, when its distance will be 94,500,000 miles (152,100,000 km).

**Mercury** is in superior conjunction on 15 July, and will not be visible during the month.

**Venus** is now theoretically an evening star, but even at the end of the month it sets less than an hour after sunset.

**Mars** is an evening star moving direct in Leo throughout July. It passes less than a degree north of Regulus on 5 July, when the



*Mars, July-September, 1976*

planet sets about two hours after sunset. It will be seen that Regulus is brighter than Mars (magnitudes: Regulus  $+1.3$ , Mars  $+1.9$ ). By the end of the month the planet sets about an hour after the Sun, and this state of affairs continues for the next few months.

**Jupiter** is now a conspicuous object in the morning sky. At the beginning of the month it passes into Taurus, and by the end of July it rises to the north of east at midnight, its magnitude being then  $-1.9$ .

**Saturn** is in conjunction on 29 July, and will not be visible during the month.

#### VIKING TO MARS

Mars is now a long way from the Earth, and is very far from being the brilliant object that it was last winter. Not even giant telescopes will show much on its disk, and at present it is very little brighter than the Pole Star; the close conjunction with Regulus on 5 July demonstrates how tremendously it has faded. The next opposition will not take place until 2 January 1978.

Nevertheless, this is an important month in the history of Martian exploration. On 4 July the first Viking soft-landing probe is scheduled to touch down in the region of Chryse, near the well-known dark markings which have long been known as the Margaritifer Sinus and the Auroræ Sinus. A second Viking will follow, this time destined to land in the area of Cydonia. If all goes well, these vehicles should give a final answer to the age-old question: *Is there any form of life there?*

Inevitably, these words are being written in 1975, and it is impossible to say just how well (or how badly) the mission will have gone by the time that the *Yearbook* appears in print. There are a great many hazards in an operation of this kind, and it is, of course, something which the Americans have yet to carry out. The Russians have soft-landed probes on Venus, and have also brought vehicles down on Mars, though unfortunately little has been learned from the Martian probes. All the American planetary

probes have been fly-by vehicles or orbiters, so that Viking is, for them, a completely new departure.

Each Viking space-craft is made up of an orbiter and a lander. The actual touch-down manoeuvre will be complicated; the Martian atmosphere is dense enough for parachutes to be useful, and a heat shield is necessary, so that the procedure differs from that for the airless Moon; but rocket braking must be used as well – as the Russians have already shown.

The orbiting section of the Viking will remain in a closed path round Mars, moving in an orbit which ranges between 1,500 and over 30,000 kilometres from the planet; the period of revolution will be one Martian day – 24·6 hours. It will send back information in the same way that the Mariner 9 probe did, but it will have an extra task, as it will also have to act as a relay for the lander.

When the lander separates from the orbiter, it will be 'on its own'. The descent starts with the lander still inside its protective aeroshell, and the main parachutes are due to open at a height above the ground of 6,500 metres. Then, at 1,700 metres, the lander separates from the parachute, and completes the drop to the Martian surface by using its own descent engines. Throughout the final descent, analysis of the Martian atmosphere will be carried out.

Once on the surface, there will be much for the lander to do. The atmosphere will again be analysed for both density and composition; windspeeds will be measured, and seismometers will be used to find out whether Mars is an active world. Photographs of the surrounding area should be clearly received, and then will come the most fascinating experiment of all, when ground samples are scooped in and analysed for any traces of life.

What is the result likely to be? So far we can do little more than guess. The canals and the intelligent Martians have disappeared from serious science; but Mars, perhaps alone of our neighbour worlds, may prove to support very lowly organic matter – even if most modern astronomers tend to be pessimistic.

With reasonable luck, 1976 should provide the answer. Even

if not, further Vikings will be dispatched. They will have much to tell us.

#### REGIOMONTANUS

There are not very many astronomical anniversaries this year, but we must certainly pay tribute to a great man who died on 6 July 1476: Johannes Müller, better known by his Latinized name of Regiomontanus. He was born in 1436 at Königsberg in Germany, and was educated at Leipzig. At the age of twenty-six he went to Italy, and spent some time there, after which he came back to his homeland and settled at Nürnberg, where he established an observatory. He carried out a great deal of valuable work, but undoubtedly his major service to science was in the field of publishing.

In those days printed books were relatively scarce, and it is probably true to say that Regiomontanus was the first large-scale astronomical publisher. Among the books which he printed, the most famous was the series of *Ephemerides*, which later Spanish and Portuguese navigators found remarkably useful; they were certainly better than any of their predecessors. In 1475 the Pope summoned him to Rome to carry out the long-planned reform of the calendar, but unfortunately he died in Rome shortly afterwards, before he could begin the work. Fittingly, he is commemorated by a large crater on the surface of the Moon adjoining that named after Purbach, whose textbook on astronomy Regiomontanus completed after Purbach's death. Yet despite his foresight and his undoubted mathematical genius, it seems that Regiomontanus never accepted the Copernican system, and firmly believed the Earth to lie in the centre of the universe.

## August

*Full Moon:* 9 August    *New Moon:* 25 August

**Mercury** is at greatest eastern elongation ( $27^\circ$ ) on 26 August. The planet is then an evening star, but is well south of the Sun and badly placed for observation in these latitudes.

**Venus** is an evening star, but continues to set less than an hour after sunset. This slow change in the elongation of Venus from the Sun about the time of superior conjunction is typical of this planet.

**Mars** is also an evening star, in the same part of the sky as Venus, and setting in the west about an hour after the Sun. Mars passes from Leo into Virgo during the month, but its magnitude is now only  $+1.9$ .

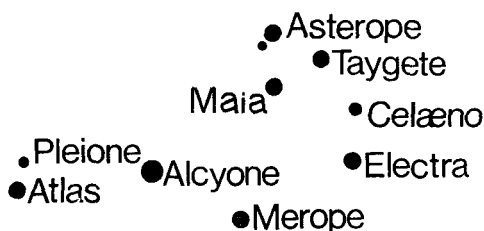
**Jupiter** now rises in the late evening in a dark sky. It will be found to the north of east in Taurus, about five degrees south of the Pleiades, and grows brighter during the month (magnitude  $-1.9$  to  $-2.1$ ).

**Saturn** now begins to appear as a morning star, moving quite rapidly out from the Sun. By the end of the month it rises in the east nearly three hours before sunrise. Saturn is moving direct in Cancer, and will be seen near the two stars Gamma and Delta Cancri and the star cluster M44, known as the 'Beehive'. Saturn passes about a degree south of M44, and about half a degree north of the star Delta (see diagram on page 62).

## PRÆSEPE AND THE PLEIADES

This month, by coincidence, the two largest planets are near two of the brightest open clusters. Jupiter lies in Taurus, near the Pleiades, and Saturn is in Cancer, close to the famous cluster Præsepe. This means that both are morning objects, though Jupiter has attained a very respectable altitude by the early hours.

Both the Pleiades and Præsepe were included in Messier's list of clusters and nebulae; they are, respectively, M.45 and M.44. Of course, the Pleiades are the more prominent, and are commonly nicknamed the Seven Sisters. They were mentioned by Hesiod and also by Homer; there are many legends about them. According to one story they were beautiful sisters who were being hotly pursued by the giant Orion when they were saved by being changed into stars and put into the sky – doubtless to Orion's intense annoyance! The brightest star of the cluster is Alcyone; then follow Electra, Atlas, Merope, Maia, Taygete, Celæno, Pleione and Asterope. Keen-sighted people can see more than seven stars with the naked eye; the record is said to be nineteen, though anyone who can glimpse as many as ten can be well satisfied.



*The Pleiades (North is at the top)*

The distance of the cluster is rather more than 400 light-years, and altogether the Pleiades group contains several hundreds of stars, together with nebulosity which shines by reflecting the light of the stars embedded in it. The leaders of the cluster are hot and white. In the 1840s Johann Mädler, best remembered for his pioneer work on mapping the Moon (carried out together with

his colleague Wilhelm Beer) put forward the theory that Alcyone was the central star of the Galaxy, but this idea met with limited support, and has long since been found to be wrong. Pleione is of special interest; it is apparently in very rapid rotation, and spins on its axis about a hundred times as quickly as the Sun. Needless to say, this information is drawn from spectroscopic observations; Pleione, like other stars, looks like nothing more than a point of light – even though it is probably shaped like an egg. It is, incidentally, variable, and occasionally throws off ‘shells’ of material which expand and finally dissipate into space.

The Pleiades cover a considerable area of the sky, and are probably best observed with binoculars or with a rich-field telescope. Using a higher magnification means that not all the cluster can be contained in the field of view at any one time, so that the full beauty is lost. With a larger telescope it is often best to use the finder.

Præsepe, in Cancer (the Crab) is also an open cluster, but differs in many ways from the Pleiades. For one thing it is not so bright, though it is easily visible with the naked eye on a dark night; the two stars Gamma and Delta Cancrī (Asellus Borealis and Asellus Australis) act as guides to it – Delta is the brighter of the two. Like the Pleiades, Præsepe was known in ancient times, and was mentioned by writers such as Theophrastus and Aratus in the period before 200 B.C.

Unlike the Pleiades, Præsepe contains no nebulosity, and many of its stars are yellow or orange, so that the cluster seems to be much older than the Pleiades. Its distance from us is rather more than 500 light-years, so that it is more remote than the Pleiades. It, too, is best seen with a rich-field telescope, and binoculars show it well. It has been nicknamed the ‘Beehive’ or the ‘Manger’.

The third famous northern cluster is the Hyades, which extend in a sort of V-formation from the brilliant Aldebaran in Taurus. Actually, Aldebaran is not a member of the cluster, and lies in the foreground; it is almost midway between the Hyades and ourselves. For some reason Messier did not include the Hyades in his list. (Possibly he thought that since the cluster is rather scat-

tered there is no possible chance of confusing it with one of the comets in which he was so interested.) There are various other naked-eye open clusters, such as M.35 in Gemini; but the Pleiades, the Hyades and Præsepe are the best examples of the class so far as northern-hemisphere observers are concerned. In the far south there is the lovely 'Jewel Box', Kappa Crucis in the Southern Cross, which is unfortunately never visible from Europe or the United States.

## September

*Full Moon:* 8 September    *New Moon:* 23 September

*Equinox:* 22 September

**Mercury** is at inferior conjunction on 22 September, and will not be visible until the end of the month, when there is some possibility of observing it as a morning star (see October note).

**Venus** continues to set in the west less than an hour after the Sun. The planet passes less than half a degree north of Mars on 10 September, but there is very little hope of seeing this conjunction in the bright twilight.

**Mars** sets less than an hour after the Sun and is not likely to be seen, as it is only of magnitude +1.9. Mars is moving direct in Virgo, and passes about three degrees north of Spica on 27 September.

**Jupiter** rises in mid-evening and reaches a stationary point on 19 September. It will then be seen in Taurus, to the south and east of the Pleiades, forming a pleasing group with this star cluster and with Aldebaran farther to the east. At the end of September Jupiter will be moving retrograde, and its brightness increases to magnitude -2.2.

**Saturn** is a morning star, rising an hour or so after midnight. It is moving direct in the eastern part of Cancer towards Regulus (magnitude of Saturn +0.6).

## THE TILTS OF THE PLANETS

The autumnal equinox occurs on 22 September; the Sun then crosses the celestial equator, moving from north to south. This is also known as the First Point of Libra, though precession has long since shifted it out of Libra into the adjacent constellation of Virgo (just as the vernal equinox, or First Point of Aries, now lies in Pisces).

The Earth's equator is tilted to the plane of the orbit by  $23\frac{1}{2}$  degrees, and this tilt is, of course, the main cause of the seasons; the Earth's changing distance from the Sun is not the chief factor, because our orbit is not far from circular. (The effect is much more important for Mars, with its greater orbital eccentricity.) Were the axial tilt different, the seasons too would be different; and this is the case for some of the other planets. The latest axial inclination values are as follows:

|         | <i>Inclination of equator to orbital<br/>plane, in degrees and minutes</i> |
|---------|----------------------------------------------------------------------------|
| Mercury | 0°                                                                         |
| Venus   | 178° 00'                                                                   |
| Earth   | 23° 27'                                                                    |
| Mars    | 24° 46'                                                                    |
| Jupiter | 3° 04'                                                                     |
| Saturn  | 26° 44'                                                                    |
| Uranus  | 97° 53'                                                                    |
| Neptune | 28° 48'                                                                    |

For Pluto we have no information since no surface features can be observed.

Some interesting facts emerge from these figures. The tilts of the Earth, Mars, Saturn, and Neptune are of the same order, so that the seasons should be of the same basic type; they are indeed so in the case of Mars, though they are much longer (the Martian year is equal to 687 Earth-days) and, as we have noted, there is an extra effect due to the fact that the distance between the planet and the Sun shows a fairly wide range. Jupiter goes round the

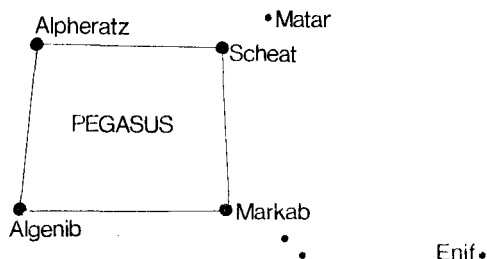
Sun almost 'upright', and so apparently does Mercury. The two oddities are Venus and Uranus. Venus, too, is 'upright' – or, as might be said, upside-down; it spins in the opposite sense to the Earth, and if modern results are correct the rotation period is 243 days, longer than Venus' year of less than 225 days. Since the axial inclination of Uranus is more than a right angle, its rotation too is technically retrograde, though it is not usually reckoned as such. The calendar there is peculiar indeed; each polar night lasts for more than 20 Earth-years, with a corresponding 'midnight sun' at the opposite pole.

Why do the planets show these various axial inclinations? We have to admit that we do not know, and theoretical astronomers would very much like to find out. The rotation periods, too, differ enormously; Venus is the slowest spinner, and Jupiter, with its 'day' of less than ten hours, is the quickest.

#### THE SQUARE OF PEGASUS

During autumn evenings Pegasus dominates the southern part of the sky, from the point of view of European and North American observers. In mythology it was the winged horse which carried

•  
•  
ANDROMEDA •



the hero Bellerophon in his battle with the three-headed, fire-breathing Chimæra. In the sky it takes the form of a square, which is very distinctive but not outstandingly brilliant; people who do not know it, and set out to find it, often expect it to be smaller and brighter than it really is.

The Square stars are Beta (Scheat), Alpha (Markab), Gamma (Algenib) and Delta (Alpheratz) – though Delta has now been officially transferred to the adjacent constellation of Andromeda, and is always known as Alpha Andromedæ. There are two other stars in Pegasus above the third magnitude, Epsilon (Enif) and Eta (Matar).

The Square stars are not genuinely associated, and it is of interest to list their distances, together with their apparent magnitudes and also their absolute magnitudes. (The absolute magnitude is the apparent magnitude which the star would have if it were seen from a standard distance of 10 parsecs, or 32.6 light-years.)

| <i>Star</i> | <i>Distance,<br/>light-years</i> | <i>Apparent<br/>mag</i> | <i>Absolute<br/>mag</i> |
|-------------|----------------------------------|-------------------------|-------------------------|
| Alpheratz   | 90                               | 2.06                    | −0.1                    |
| Scheat      | 210                              | var., 2.3–2.7           | −1.5                    |
| Markab      | 109                              | 2.50                    | −0.1                    |
| Algenib     | 570                              | 2.84                    | −3.4                    |

Algenib, which appears the faintest of the four, is really much the most luminous. Alpheratz, Markab, and Algenib are of spectral type B, and are hot and white; Scheat is a vast Red Giant, and, like many of its class, is somewhat variable. Its spectrum is of type M, and the colour is very obvious when the star is observed through binoculars or a telescope. The diameter of Scheat is well over 100,000,000 miles, but its mass is only 9 times that of the Sun.

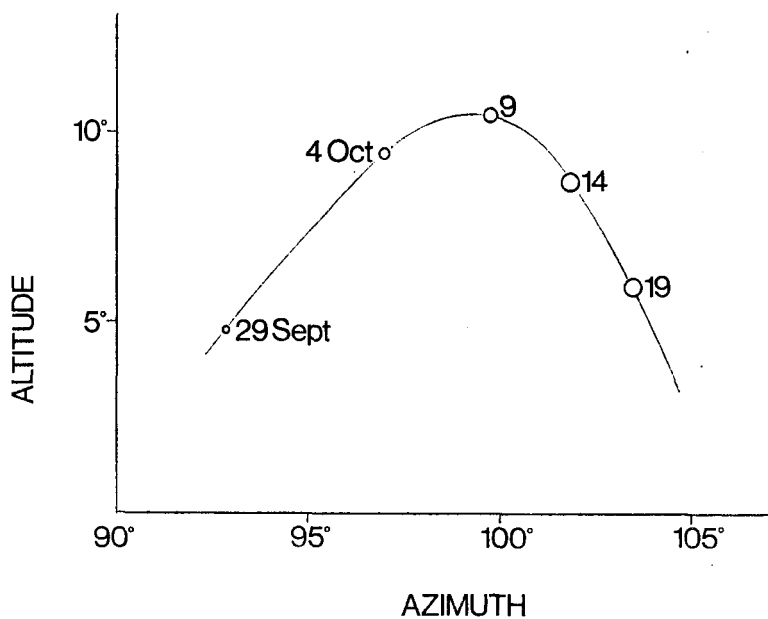
It is interesting to note how many stars can be seen with the naked eye inside the Square. There are fewer of them than might be thought.

## October

*Summer Time* in Great Britain and Northern Ireland ends on 24 October.

*Full Moon:* 8 October    *New Moon:* 23 October

**Mercury** is at greatest western elongation ( $18^\circ$ ) on 7 October, and this offers a favourable opportunity to see this planet as a morning star. The diagram shows the changes in altitude and azimuth of



*Mercury, October, 1976*

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**Mercury** on successive mornings when the Sun is six degrees below the horizon; this is about 35 minutes before sunrise in October. The changes in brightness are roughly indicated by the size of the circles, and it will be noticed that Mercury is brightest *after* the date of western elongation.

**Venus** now begins to be more readily observable as it moves slowly out from the Sun. Venus passes about three degrees north of Antares on 28 October, and by this time it will set in the south-west more than an hour after sunset (magnitude  $-3.4$ ).

**Mars** moves into Libra in the early part of October, but it is now approaching conjunction, and sets shortly after the Sun.

**Jupiter** is now approaching opposition and is a brilliant object, rising to the north of east in the early evening. It is moving retrograde in Taurus, and at the end of the month will again be seen a few degrees south of the Pleiades. Jupiter continues to grow brighter as the Earth's distance decreases, and by the end of October the planet will reach magnitude  $-2.4$ .

**Saturn** rises at midnight in early October and will be seen to the north of east on the borders of Cancer and Leo. The distance of the planet is slowly diminishing, but the change is too small to affect the brightness of Saturn, which remains for some time at magnitude  $+0.6$ .

A **total eclipse of the Sun** on 23 October will be visible along a path which begins in Tanzania and crosses the Indian Ocean to the most southerly part of Australia, and ends in the Pacific Ocean north of New Zealand. There will be a large partial eclipse in other parts of Australia and in New Zealand. See notes on page 109.

### THIS MONTH'S TOTAL ECLIPSE

It is a great pity, from the point of European observers, that

the October eclipse will not be seen from anywhere on the Continent, since it will be relatively long – though not so long as the eclipse of 1973. However, many expeditions will be sent to observe it. Despite all the sophistication of modern equipment, there are still researches which can be carried out only during totality, and astronomers are always anxious to make the most of their limited opportunities.

Records of solar eclipses go back a very long way, even though the causes were not known until Greek times. One famous story dates back to 2136 B.C. It is said that the astronomers of the Chinese court, Hsi and Ho, failed to predict an eclipse – and were summarily executed; the Chinese believed that a dragon was trying to eat the Sun, and that the only remedy was to make enough noise to scare the attacker away. The story has been told many times, though its veracity is open to serious doubt!

The so-called Saros period provides a rough means of predicting eclipses (and was, presumably, the method which Hsi and Ho were expected to use). Obviously, a solar eclipse can happen only when the new moon is very near a node – that is to say, a point where the Moon's orbit crosses the plane of the orbit of the Earth. Because of gravitational effects, the nodes of the Moon's orbit shift round slowly and regularly. It so happens that after 18 years 11·3 days, the Earth, Moon, and Sun return to almost the same relative positions, so that a solar eclipse is apt to be followed by another eclipse one Saros later. Of course, the Saros is not perfect, and the eclipses are not identical repeats of each other; for instance, the 1927 eclipse was total over Yorkshire, but the 'return' eclipse of 1945 was only partial there. However, the method is better than nothing at all, and it was used by Thales of Miletus, first of the great Greek philosophers, to predict an eclipse for 28 May, 585 B.C. (The date has been challenged, but most scholars seem now to be in agreement.) At that moment there was a battle in progress between the Lydians and the Medes, but when 'day was turned into night' the opposing armies were so impressed that they concluded a hasty peace.

Yet the early Greeks had no idea of the cause of eclipses.

Anaximander (*circa* 611–546 B.C.) believed that the Sun was 'like a chariot-wheel, the rim of which is hollow and full of fire, and lets the fire shine out at a certain point in it like the nozzle of a pair of bellows'; an eclipse occurred when a hole was temporarily blocked up. Later Greek scientists were better informed, and from then onward eclipse records are reasonably complete.

During totality, the prominences may be seen; they used to be called 'red flames', though they are in fact masses of glowing gas. For many years their nature was uncertain, and they were commonly attributed to a lunar atmosphere; not until the nineteenth century was it finally established that they belong to the Sun. Following the eclipse of 1868, Janssen (France) and Lockyer (England) discovered that by using the spectroscope it is possible to study prominences at any time, and the chromosphere also is available; but the outer corona is so faint that it cannot be studied away from totality – except, of course, by observers who have moved out beyond the atmosphere of the Earth.

Only two total eclipses have tracks passing over England in our own century. The first was, of course, that of 1927; the next will be on 11 August 1999, when the track will cross Cornwall. No doubt there will be intense interest – and would-be viewers will be well advised to book hotel accommodation well ahead of time!

#### DIPHDA

Two bright stars are visible in the southern evening sky this month, well below the Square of Pegasus. One is Fomalhaut in Piscis Austrinus (the Southern Fish); some notes about it were given on page 94 of the 1975 *Yearbook*. The other is Diphda, leader of the vast, sprawling constellation of Cetus, the Whale (sometimes identified with the fearsome sea-monster of the Perseus and Andromeda legend).

Diphda may be found by following down the line from Alphe-  
ratz, in the Square, through Algenib. It is of the second mag-  
nitude (2.02) and has a K-type spectrum, so that it is somewhat  
orange in hue. Its absolute magnitude is 0.8, and its distance from  
us is 57 light-years.

Diphda is interesting because it is suspected of variability. There have been reports that for brief periods it increases in brightness, reaching the first magnitude. These reports are very probably wrong; all the same, Diphda is worth watching – though comparisons are not easy, because there are no comparable stars anywhere near it.

There should be no chance of confusing Diphda with Fomalhaut. Of the two Fomalhaut is lower down, white in colour, and very much the more brilliant of the two, even though it is never seen to advantage from anywhere in the British Isles, and from North Scotland it barely rises above the horizon.

## November

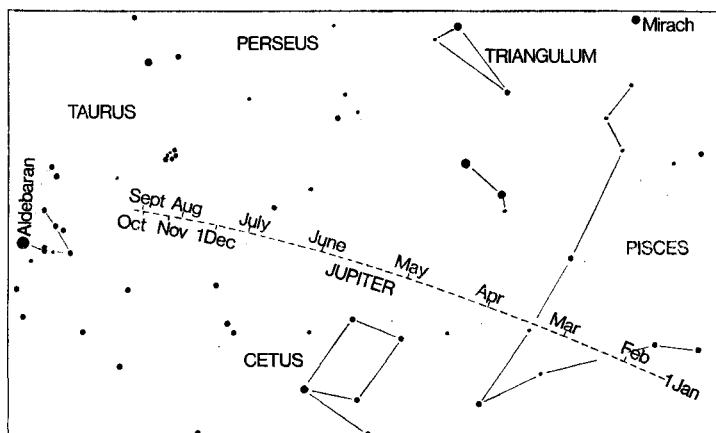
*Full Moon:* 6 November *New Moon:* 21 November

**Mercury** is in superior conjunction on 7 November and will not be visible during the month.

**Venus** has now moved out from the Sun and is moving rapidly north. By the end of the month it sets in the south-west more than two hours after sunset (magnitude  $-3.6$ ).

**Mars** is in conjunction on 25 November and will not be visible during November.

**Jupiter** comes to opposition on 18 November, and is then at its



*Jupiter, 1976*

brightest (magnitude  $-2.4$ ). This is not quite as bright as it was at the last opposition, since its distance of 374 million miles (602 million km) is about six million miles greater than it was in 1975. The planet continues to move retrograde in Taurus, and forms a conspicuous group with the Pleiades and Aldebaran. The dark evenings afford an opportunity to observe the continuous changes in the positions of the four great satellites, which are readily seen with binoculars or a small telescope.

**Saturn** now appears to move more slowly, and it reaches a stationary point on the borders of Cancer and Leo on 28 November. The planet rises in the late evening to the north of east, and should be easily recognized near the Sickle of Leo. Saturn is growing brighter (magnitude  $+0.6$  to  $+0.5$ ) and is quite noticeably brighter than Regulus.

**A penumbral eclipse of the Moon** on night of 6-7 November is not likely to be noticed, since the change of light in such an eclipse is very small. This Full Moon occurs with the Moon at apogee, 252,400 miles from the Earth. This is more than 30,000 miles farther than it was at the Full Moon in March, and its change in apparent size should be quite noticeable. Unfortunately, this change is often masked by other effects due to mist near the horizon, or the proximity of other objects, but the variation in size can be measured and is quite apparent on photographs.

#### THE RED SPOT ON JUPITER

Now that Jupiter is back at opposition it will be closely studied by planetary observers. It has moved back into the northern hemisphere of the sky, so that it is favourably placed so far as Europe and the United States are concerned: and its disk shows abundant detail. There are the darkish belts, the bright zones, the spots and the festoons; Jupiter is always changing, and there is never a lack of something new to see.

Much the most famous of all Jovian features is the Great Red

Spot, which has been under observation for several centuries; it was observed by Robert Hooke in 1664, and was probably seen even earlier. Sometimes it disappears temporarily, but it always comes back, and for many years now it has been very prominent. Its latitude varies little from 22 degrees south, but it drifts about in longitude, and at the beginning of 1975 was at around 028 degrees. At its greatest extent it is 30,000 miles long and 8,000 miles broad, so that its surface area is greater than that of the Earth.

The Spot has long been a mystery, particularly as it is unique on Jupiter. Before the Pioneer flights, there were two main theories about it. One was that the Spot was a solid or semi-solid body floating in Jupiter's outer gas; this would explain its changes in visibility, since slight variations in the density of the surrounding medium would cause it to change in level. When it sank, it would be covered up, and would vanish; when it rose once more, it would reappear. The late B. M. Peek, a famous English amateur who specialized in observations of Jupiter (and wrote a classic book about it) compared the situation with that of an egg immersed in a jug of water. Adding salt to the water, and making it denser, causes the egg to rise to the top of the jar!

The alternative theory was that the Spot is nothing more nor less than the top of a 'Taylor column' of stagnant gas, caused by a disturbance in the circulation of the lower atmosphere of the planet due to some feature of the 'surface'. Now, at last, we have more information, drawn from the first Jupiter probes: Pioneer 10, which by-passed the planet in December 1973, and Pioneer 11, which made a similar fly-by a year later.

In the Pioneer pictures, the Spot shows a darkish border, pointed at both its eastern and western ends, and there is a hint of a ring of darker material within the Spot itself. Cellular structure is suggested in some of the most detailed views, and there may well be evidence of convective activity. It seems that we must abandon the 'floating island' theory; the Spot is what we may term a meteorological phenomenon, and can even be regarded as a whirling storm, though its precise origin is still unknown. Neither do we know whether it will persist indefinitely. Certainly it is very

long-lived, and its decay will be very gradual, if indeed it is decaying at all.

### THE W OF CASSIOPEIA

During November evenings the constellation of Cassiopeia is almost overhead as seen from Britain. It is easy to find; its five main stars form a distinct W or M, and they are bright enough to be reasonably prominent. The Pole Star lies almost midway between Cassiopeia and Ursa Major (the Great Bear), so that when Cassiopeia is high up the Bear is low down, and *vice versa*.

The W stars are Alpha or Shedir, Beta or Caph, and Gamma (all of about the second magnitude), Delta ( $2\frac{1}{2}$ ) and Epsilon ( $3\frac{1}{4}$ ). Shedir is orange, with a K-type spectrum; to the casual observer the other members of the W are pure white, though in fact Beta has a spectrum of type F and is therefore very slightly yellowish.

Gamma is an unstable star. For many years now its magnitude has been around 2.3, but it shows occasional outbursts – as in 1936, when it rose to magnitude 1.6; this was followed by a slow fall to magnitude 3, and there was an even slower subsequent rise. Alpha (Shedir) has long been suspected of slight variability, but the range is only a few tenths of a magnitude at most, and some observers doubt whether it is variable at all.

The Milky Way flows through Cassiopeia, and there are many rich star-fields here as well as other interesting telescopic objects. In mythology Cassiopeia was the wife of King Cepheus, and mother of Andromeda.

### THE SHEPHERD-BOY ASTRONOMER

This year is the 200th anniversary of the death of James Ferguson, who was born near Rothiemay, in Banffshire (Scotland) in 1710 and whose father was a farm labourer. James became a shepherd-boy at the age of ten, and it was while he was guarding his sheep at night that he began studying the stars. At the age of fourteen he was employed by a farmer who encouraged him to go on with his studies, and a local butler taught him the rudiments of mathematics. Evidently he was an apt pupil; he went to Edinburgh

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and then to London, making himself a great reputation as a builder of astronomical clocks, sundials, and orreries. He then turned to writing, and his *Astronomy Explained upon Sir Isaac Newton's Principles* became accepted as a standard text. Ferguson was, in fact, the first great 'astronomical popularizer', and as such he made a most valuable contribution to science. He died in London on 16 November 1776.

## December

*Full Moon:* 6 December    *New Moon:* 21 December

*Solstice:* 21 December

**Mercury** is at greatest eastern elongation ( $20^\circ$ ) on 20 December, and it may be possible to catch a glimpse of the planet as an evening star low in the south-west just after sunset for a few days about this time.

**Venus** is approaching eastern elongation in January, and is now a brilliant evening star readily seen in the south-west at sunset. By the end of the year it sets four hours after the Sun and reaches magnitude  $-3.9$ .

**Mars** is now a morning star but at the end of December it rises in the south-east less than an hour before sunrise. The next opposition of Mars does not occur until 1978.

**Jupiter** is a brilliant evening star, visible for most of the night in Taurus. The planet is moving retrograde, and by the end of the month will reach the borders of Taurus and Aries, setting in the west about three hours before sunrise. Jupiter will be seen less than a degree north of the Moon (then nearly at the Full) on the night of 5 December. The next opposition of Jupiter will occur on 23 December 1977.

**Saturn** rises in the east in mid-evening on the borders of Leo and Cancer. The planet is moving retrograde quite slowly, and there is little change in its grouping with Regulus and the Sickle of Leo.

Saturn is growing brighter (magnitude  $+0.5$  to  $+0.3$ ) as it approaches opposition in February 1977.

**The minor planet Vesta** reaches magnitude 6.6 at the end of the year, and it should be possible to find the planet with a pair of binoculars. It is moving retrograde in Gemini, and its position during the month is shown in the diagram on page 57.

#### RHÆTICUS AND THE COPERNICAN SYSTEM

This month is the 400th anniversary of the death of one of the characters in the story of the 'Copernican revolution', which ended in the overthrow of the Ptolemaic system in which the Sun was believed to move round the Earth. Georg Joachim von Lauchen died on 4 December 1576. Because he was born in the province of Rhaetio, we usually remember by the Latinized version of his name: Rhæticus.

He studied at Nürnberg, and then went on to become professor of mathematics at the University of Wittenberg, where he arrived in 1536. As he was only 22 years old, he was young for such an appointment, but his ability was unquestioned. Three years later he heard of the remarkable new theory being worked out by an obscure Polish canon, Copernicus, who lived at Frombork, one of the less accessible parts of Poland. Could the Sun, not the Earth, be the centre of the Solar System? Rhæticus was intrigued, and he made up his mind to investigate, so he made contact with Copernicus and went to Frombork. He was warmly received, and he stayed for two years instead of paying a fleeting visit.

Copernicus was in his mid-sixties, and his duties at Frombork were many and varied, but he was somewhat isolated mentally, and it is said that 'he felt revulsion toward any form of familiarity and any frivolous and pointless conversation'. No doubt he was glad to see Rhæticus, and to have someone of his own mental status with him.

Rhæticus urged him to publish his work. Copernicus' book on the subject was complete; but he hesitated to make it public, because he knew very well that the reaction of the Church would

be hostile – and Copernicus himself was in Holy Orders. Nevertheless, Rhæticus persisted, and as a first step he wrote a short book of his own, which he called the *Narratio prima* (First Account) in which the new theory was simply and concisely described. It was duly printed, and soon sold out. At last Copernicus consented to publish his own book, and Rhæticus took the manuscript to a Nürnberg publisher named Petrejus, who was anxious to produce it.

Rhæticus meant to see the book through the press, but he was unable to do so, because in 1541 he left Wittenberg to take up a new post in Leipzig. He handed over the supervision to a Lutheran clergyman named Osiander, and it was Osiander who added the famous unauthorized preface, stating that the theory was merely an aid to calculation rather than literal truth. Probably Copernicus never knew what had happened; he died on 24 May 1543, just as the book was coming off the press.

Rhæticus himself continued to champion the Copernican system, and calculated planetary tables based upon it rather than on the old Ptolemaic theory. He also undertook other valuable investigations; but he will be best remembered as the man who had a great deal to do with making Copernicus' work available to the world.

### THE GREAT NEBULA

Orion is back in the evening sky; with its two brilliant leaders, the red Betelgeux and the pure white Rigel, together with the starry Belt and the misty Sword, it is perhaps the most glorious of all the constellations. Also, it acts as an invaluable guide to less prominent groups, and it cannot be mistaken.

The Sword of Orion contains the Great Nebula, Messier 42, which is clearly visible with the naked eye. Even a modest telescope will show the 'Trapezium' – the multiple star Theta Orionis, which lies inside the Nebula on the Earth-facing side, and which lights up the nebular material. The Nebula itself seems to have been first described by Nicholas Peiresc in 1610, though earlier observers, including Ptolemy, had seen it and had classed it as a 'misty star'. Its distance from us is about 1500 light-years.

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There is little doubt that star formation is going on inside the Nebula, and recent infra-red studies have shown that there are other fascinating objects as well. In particular there is Becklin's Object, which cannot be seen visually because the nebular material hides it, but which is detectable in the infra-red. There are two theories about it. It may be a very young star, still condensing toward the Main Sequence, and not yet hot enough to emit visible light; or it may be an intensely luminous star – perhaps a million times more powerful than the Sun – which is simply masked. On the whole the latter idea seems the more probable, but there is a divergence of opinion among astronomers. Whatever Becklin's Object may be, it is of tremendous significance – and it is a great pity that we cannot see it directly.

### THE PLANETS IN THE NORTHERN HEMISPHERE OF THE SKY

There was a period, in the early 1970s, when the brightest superior planets were in the southern celestial hemisphere. Now the conditions are reversed, and it is the northern sky which is favoured. Venus, too, has north declination at the moment.

The next oppositions of the bright superior planets are as follows:

| <i>Planet</i> | <i>Next opposition</i> | <i>Constellation</i> |
|---------------|------------------------|----------------------|
| Mars          | 1978 Jan. 22           | Gemini/Cancer        |
| Jupiter       | 1977 Dec. 23           | Aries                |
| Saturn        | 1977 Feb. 2            | Cancer               |

It is true that the telescopic planets are in the south; Uranus in Libra, Neptune in Ophiuchus and Pluto in Virgo. However, it cannot be denied that during the coming year northern observers will have far better opportunities than their colleagues in the southern hemisphere.

## Eclipses in 1976

In 1976 there will be three eclipses, two of the Sun and one of the Moon; there is also a penumbral eclipse of the Moon.

- (1) *An annular eclipse of the Sun* on 29 April, the central track crossing north-western Africa from Dakar to Tripoli, through Turkey and the extreme south of the U.S.S.R., to end in the Sinkiang province of China. Visible as a partial eclipse in Europe and the greater part of Asia and Africa. In southern England the eclipse begins at 9<sup>h</sup> 01<sup>m</sup> and reaches its maximum at 10<sup>h</sup> 13<sup>m</sup>, when 40 per cent of the Sun will be obscured by the Moon; the eclipse ends at 11<sup>h</sup> 29<sup>m</sup>. At more northerly stations in the British Isles, the magnitude of the eclipse will be somewhat less, and it will begin a few minutes later and end earlier.
- (2) *A partial eclipse of the Moon* on 13 May will be visible in Australia, Asia, Africa, and Europe, but only 13 per cent of the Moon's disk will be darkened by the Earth's shadow. In the British Isles the Moon will be in eclipse as it rises. This eclipse begins at 19<sup>h</sup> 16<sup>m</sup>, reaches its maximum at 19<sup>h</sup> 54<sup>m</sup>, and ends at 20<sup>h</sup> 33<sup>m</sup>.
- (3) *A total eclipse of the Sun* on 23 October will have a maximum duration of 4<sup>m</sup> 46<sup>s</sup>. The line of totality begins in Tanzania and crosses the Indian Ocean to the extreme south of Australia, ending in the Pacific Ocean north of New Zealand. The central line of totality passes some miles north of Melbourne, where the eclipse will be total for 2<sup>m</sup> 39<sup>s</sup>. A large partial eclipse will be seen in other parts of Australia,

and a rather smaller eclipse in New Zealand, where the Sun will set before the end of the eclipse.

- (4) There is also *a penumbral eclipse of the Moon* on the night of 6 November, but special equipment is normally needed to detect the small loss of light in the penumbral shadow.

## Occultations in 1976

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path and the timing of these occultations is useful in fixing the position and motion of the Moon. The Moon's orbit is tilted at more than five degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at a rate of about twenty degrees a year, a complete revolution taking 18.6 years, during which time all the stars that lie within about six and a half degrees of the ecliptic will be occulted. The occultations of any one star continue month after month until the Moon's path has twisted away from the star but only a few of these occultations will be visible at any one place in hours of darkness.

Only four first magnitude stars are near enough to the ecliptic to be occulted by the Moon; these are Regulus, Aldebaran, Spica, and Antares. At the present time Spica is occulted by the Moon each month, the series having commenced in March 1975 in the southern hemisphere. It will continue throughout 1976, working its way north, and one of these, on 1 August, could be observed in the British Isles. The occultation occurs in broad daylight, beginning at 15<sup>h</sup> 41<sup>m</sup> and ending at 16<sup>h</sup> 53<sup>m</sup> in southern England, and a few minutes earlier in more northern latitudes. This observation will be difficult and will call for an adequate telescope.

The planets, which have a motion of their own, do not give rise to lengthy series of occultations, but during 1976 the slow-moving Neptune and Uranus are occulted on a number of occasions, while Jupiter and Mercury are also eclipsed in this way. Of these, only the occultation of Jupiter on 27 May will be observable in Britain, and only the reappearance of the planet at the dark limb of the Moon is predicted at 3<sup>h</sup> 26<sup>m</sup> in the south of England. The Moon will then be a slender crescent, less than

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two days before New Moon, and this, too, will be a difficult observation.

Details of occultations of all stars brighter than magnitude 7.5 are given annually in the *Handbook* of the British Astronomical Association (for Great Britain, Australia and New Zealand), and in the special supplement issued by *Sky and Telescope* for observers in the United States and Canada. This Special Supplement is available without charge from the Director, Nautical Almanac Office, U.S. Naval Observatory, Washington, D.C. 20390.

## Comets in 1976

The appearance of a bright comet is a rare event which can never be predicted in advance, because this class of object travels round the Sun in an enormous orbit with a period which may well be many thousands of years. There are therefore no records of the previous appearances of these bodies, and we are unable to follow their wanderings through space.

Comets of short period, on the other hand, return at regular intervals, and attract a good deal of attention from astronomers. Unfortunately they are all faint objects, and are recovered and followed by photographic methods using large telescopes. Most of these short-period comets travel in orbits of small inclination which reach out to the orbit of Jupiter, and it is this planet which is mainly responsible for the severe perturbations which many of these comets undergo. Unlike the planets, comets may be seen in any part of the sky, but since their distances from the Earth are similar to those of the planets their apparent movements in the sky are also somewhat similar, and some of them may be followed for long periods of time.

The number of comets under observation in any one year is much greater than is generally supposed. The following table compares the numbers of newly discovered comets, successfully predicted returns of periodic comets, and comets being followed from previous years:

|                         | 1970 | 1971 | 1972 | 1973 |
|-------------------------|------|------|------|------|
| New discoveries         | 6    | 1    | 6    | 9    |
| Predicted and recovered | 11   | 5    | 6    | 6    |
| Still under observation | 10   | 14   | 10   | 13   |
| Totals                  | 27   | 20   | 22   | 28   |

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Three of the new comets in 1973 proved to be short-period comets, one of which had been lost since 1890. Data for 1974 are not yet complete, but five new comets were discovered and four others recovered as a result of successful predictions.

In 1976 the following periodic comets are expected to return to perihelion:

*Comet Gunn* was found in 1970 on plates taken with the 48-inch Schmidt telescope at Palomar. This comet has the small eccentricity of 0.32, and its orbit lies entirely between the orbits of Mars and Jupiter. It can therefore be observed all round its orbit, like comets Encke and Schwassmann-Wachmann (1). *Comet Gunn* has a period of 6.8 years and it seems to have been forced into this orbit by a close approach to Jupiter in 1965.

*Comet Churyumov-Gerasimenko* was found in 1969 at the observatory at Alma-Ata in the south-east of the U.S.S.R. It was under observation for about eight months and its orbit should be well established. This comet has a period of 6.5 years and a moderate eccentricity of 0.63. It made a close approach to Jupiter in 1959, its orbit before this having a longer period.

*Comet Harrington-Abell* was discovered at Mount Palomar in 1955 and was seen again at its returns in 1962 and in 1968-69. It is a faint object travelling in an orbit with a period of 7.2 years and an eccentricity of 0.52.

*Comet d'Arrest* was discovered in 1851 and has been seen at twelve returns, the last being in 1970, when it was well observed. This comet was seriously perturbed by Jupiter in its previous orbit, and it now has a period of 6.23 years and an eccentricity of 0.64.

*Comet Schaumasse* has made six observed appearances, the first at its discovery in 1911 and the last in 1960. It was not recovered in 1968. The period of this comet is 8.18 years and the

eccentricity of the orbit is 0.705 – somewhat larger than the average for the short-period comets.

*Comet Klemola* was found on plates taken at the Yale Columbia Southern Station in Argentina in 1965, but was observed for only a few weeks. This comet has the much longer period of eleven years, and is expected to return to perihelion in the summer of 1976.

*Comet Pons-Winnecke* was first seen by Pons in 1819 and was found again by Winnecke in 1858. It has been seen at fifteen subsequent returns, the last being in 1970 when it was under observation for most of the year. This comet is interesting because it is perturbed by Jupiter at each alternate revolution (the period being about half that of Jupiter), with the result that the orbit is becoming larger, more circular and more inclined to the ecliptic. In 1819 the orbit had a period of 5.56 years, and at perihelion it came well within the Earth's orbit, almost to the orbit of Venus. The period is now 6.34 years and perihelion lies outside the Earth's orbit.

*Comet Kojima* is another new comet, discovered in 1970 in Japan by a science teacher with his home-made reflector. The comet has a period of 6.2 years with a moderate eccentricity of 0.52, and it is expected to return to perihelion at the end of 1976.

*Comet Schwassmann-Wachmann* (1) has a nearly circular orbit with a period of sixteen years, which lies entirely between the orbits of Jupiter and Saturn. The motion of this comet is very much like that of a planet, and it is visible each year. It is remarkable for its sudden outbursts of brightness, which seem to have some connection with solar activity.

## Meteors in 1976

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect the orbit of a meteor swarm, which is a concentration of meteoric dust moving in an orbit around the Sun. Such an intersection can occur only at one particular time of year, but if the dust is spread out along the orbit, the resulting shower of meteors may last for several days. The word 'shower' must not be misinterpreted – only on very rare occasions have the meteors been so numerous as to resemble snowflakes falling.

The naked-eye study of meteors is quite a laborious task, but even a casual observer, watching for, say, ten minutes on an August night, may observe a number of Perseids. If their tracks are marked on a star map, and traced backwards, a number of them will be found to intersect in a point (or a small area of the sky) which marks the radiant of the shower. This gives the direction from which the meteors have come.

The following table gives some of the more easily observed showers with their radiants; the effect of moonlight in 1976 is indicated.

| <i>Limiting dates</i> | <i>Shower</i> | <i>Maximum</i> | <i>R.A.</i>                           | <i>Dec.</i> |   |
|-----------------------|---------------|----------------|---------------------------------------|-------------|---|
| Jan. 1-6              | Quadrantids   | Jan. 4         | 15 <sup>h</sup> 28 <sup>m</sup> + 50° |             |   |
| April 20-22           | Lyrids        | April 21       | 18 <sup>h</sup> 08 <sup>m</sup> + 32° |             |   |
| July 27-Aug. 17       | Perseids      | Aug. 12        | 3 <sup>h</sup> 04 <sup>m</sup> + 58°  |             | M |
| Oct. 15-25            | Orionids      | Oct. 20        | 6 <sup>h</sup> 24 <sup>m</sup> + 15°  |             |   |
| Oct. 26-Nov. 16       | Taurids       | Nov. 8         | 3 <sup>h</sup> 44 <sup>m</sup> + 14°  |             |   |
| Nov. 15-19            | Leonids       | Nov. 17        | 10 <sup>h</sup> 08 <sup>m</sup> + 22° |             |   |
| Dec. 9-14             | Geminids      | Dec. 14        | 7 <sup>h</sup> 28 <sup>m</sup> + 32°  |             |   |
| Dec. 17-24            | Ursids        | Dec. 22        | 14 <sup>h</sup> 28 <sup>m</sup> + 76° |             |   |

M=moonlight interferes

## Minor Planets in 1976

Although many thousands of minor planets (asteroids) are known to exist, only about 2,000 of these have well-determined orbits and are listed in the catalogues. Most of these orbits lie entirely between those of Mars and Jupiter. All of these bodies are quite small, and even the largest can only be a few hundred miles in diameter. Thus they are necessarily faint objects, and although a number of them are within the reach of a small telescope, few of them ever reach any considerable brightness. Of these, the most important are the 'big four', Ceres, Pallas, Juno, and Vesta. Vesta can occasionally be seen with the naked eye, and this is most likely to occur at a June opposition, when Vesta is at perihelion.

In 1976, Vesta reaches magnitude 6.6 by the end of the year, just before it reaches opposition in January 1977. It will then be in Gemini, and it should be possible to find it with a pair of binoculars. The apparent path of Vesta at this time is shown in the diagram on page 57. Like many other minor planets, Vesta shows a small variation in its brightness with a period of 5<sup>h</sup> 21<sup>m</sup>, and this is taken to indicate that the planet rotates, the variation of light being due to its irregular shape, or perhaps to the different reflective surface of opposite faces.

Juno, the smallest of these four planets, is at opposition on 1 March, on the borders of Sextans and Leo, but its magnitude then is only 8.8. Ceres, the largest of all the minor planets, and the first to be discovered, is brightest (magnitude 6.9) in January, following its opposition the previous month. Pallas, which is distinguished from the other three by its unusually large inclination of 35° to the ecliptic, grows brighter towards the end of the year as it approaches opposition in February 1977, but it does not exceed magnitude 7.0 in December and 6.7 when at opposition.

## **Some Events of 1977**

### **ECLIPSES**

In 1977 there will be three eclipses, two of the Sun and one of the Moon. There will also be a penumbral eclipse of the Moon.

4 April – a partial eclipse of the Moon, visible in Europe, Africa, and America.

18 April – an annular eclipse of the Sun, visible in Africa, the Antarctic, and southern Asia.

12 October – a total eclipse of the Sun, visible in North America and the West Indies.

27 September – a penumbral eclipse of the Moon.

### **THE PLANETS**

*Mercury* may best be seen in northern latitudes as an evening star near its greatest eastern elongation on 10 April, and as a morning star at greatest western elongation on 21 September.

*Venus* will be an evening star at the beginning of the year, reaching eastern elongation on 24 January and greatest brilliancy on 1 March. After inferior conjunction on 6 April it will be a morning star at greatest brilliance on 11 May and western elongation on 15 June.

*Mars* will be a morning star for the first half of the year, but rises at midnight by the end of July. It grows brighter at the end of the year as it approaches opposition in January 1978.

*Jupiter* is in conjunction on 4 June and reaches opposition on 23 December in Taurus.

*Saturn* is at opposition on 2 February on the borders of Cancer and Leo, and comes to conjunction on 13 August.

*Uranus* is at opposition on 30 April in Libra.

*Neptune* is at opposition on 5 June in Ophiuchus.

*Pluto* is at opposition on 2 April in Virgo.

## **PART TWO**

### **Article Section**

Again we have articles from some of our regular contributors. Howard Miles writes on the results of the first Mariner to penetrate the inner regions of the Solar System, and Dr David Allen deals with those remarkable objects of which BL Lacertæ is the prototype. We are also delighted to welcome to our ranks Dr Garry Hunt, one of our most distinguished professional scientists, and two leading amateurs, Ramon Lane and W. E. Pennell.

There is one new departure for this issue. Comments have been made that we have never included any more technical articles, for the benefit of really well-informed readers. In the present issue, therefore, we are glad to include a review contribution from David Block, one of the best-known young astronomers in South Africa, who writes about his own particular line of research – Black Holes.

# Mariner 10 to Venus and Mercury

H. G. MILES

In this technological age it is most difficult for anyone interested in the solar system to keep fully informed on the many discoveries that are being made and the theories that are being put forward to explain these discoveries. Even if one considers just the planetary probes, the wealth of information gleaned outweighs by far all the information collected over the centuries from Earth-based observatories. The first successful planetary probe, *Mariner 2*, a relatively simple space vehicle, flew past Venus as recently as 1962 and now, fourteen years later, probes have visited all the planets out as far as Jupiter, and the last of the Jupiter probes is well on the way to Saturn and possibly Uranus. The using of the gravitational field of one planet to modify the orbit of a spacecraft so that it will visit a second planet makes it possible to visit the more distant planets without resorting to the use of larger rockets, a very important factor from a financial point of view. Alternatively, if the standard rocket were used, it would mean a smaller payload. This procedure was used for the first time with the space probe *Mariner 10*, which was first put into an orbit so that it would fly by the planet Venus. Using the gravitational field of Venus, the orbit was modified so that the probe would make a close approach to Mercury, the innermost planet and one that had not been visited before.

*Mariner 10* was launched from the Kennedy Space Center on 3 November 1973 using an Atlas-Centaur rocket. It had three main functions, to obtain information on conditions existing in the interplanetary regions between the orbits of the Earth and Mercury, to collect data on the clouds of Venus, which from

Earth-based ultra-violet light experiments seem to indicate very high rotational speeds, and lastly to study the atmosphere and surface of Mercury. The last objective was the prime one. In addition to the photographic experiments, the probe was capable of carrying out magnetic field and plasma measurements, experiments involving infra-red and ultra-violet light spectroscopy and infra-red radiometry. In addition the usual occultation experiments were carried out, but on this occasion they were supported by an experimental X-band high frequency transmitter.

As with earlier probes to Venus and Mars, the spacecraft was first put into a parking orbit round the Earth and then at the correct time the Centaur rocket was fired for the second time to put it into the Venus transfer trajectory. Within three hours of launch a start was made to calibrate and check the instruments. Five photographs of the Earth and six of the Moon were used for checking exposure times for the cameras. It was thought that the cloud-covered Earth would be a suitable target for checking the lighting conditions at Venus, and the Moon's surface would provide something similar to that expected at Mercury. How little did they know that the Moon and Mercury would be so similar.

The first mid-course manoeuvre was carried out after ten days, and this brought the probe back on to the nominal course. A second adjustment was carried out on 18 January. It was necessary to achieve a very precise approach to Venus because an error of 1 kilometre would have produced an error of about 1,000 kilometres by the time the probe reached Mercury. A successful fly-by of Venus was achieved on 5 February 1974, but there were many anxious moments during the journey.

### **The experiments**

The ultra-violet experiments consisted of two independent instruments. A fixed pointing occultation spectrometer, mounted on the spacecraft body was designed to detect any Mercurian atmosphere, if one existed. The other, an airglow instrument, was mounted on the scanning platform and was capable of measuring the distribution of hydrogen, helium, argon, oxygen, neon, and carbon com-

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pounds within the atmosphere of the planet. Close to the Earth it was used to observe the hydrogen corona of our planet and to search for helium. It was also used to measure the reflective properties of the lunar surface at ultra-violet wavelengths. During the cruise, both instruments were used to measure the distribution of hydrogen Lyman- $\alpha$  radiation originating from galactic sources and the Magellanic Clouds.

The infra-red radiometer was designed to measure the cloud-top temperatures on Venus and scan the surface of Mercury. By studying the rate of fall-off of surface temperature during Mercurian late afternoon and night, information was gained on the nature of the surface. By comparing any positions giving abnormalities with the television pictures provide extra information on these areas.

The plasma science experiment was activated soon after launch to provide continuous measurements on the solar wind. Whilst near Venus, a study of the interaction of the solar wind with the planet permitted verification of ideas obtained from earlier probes. In the region of Mercury, no data were known, so it was used to provide the basic information. The experiment contained two devices. The scanning Electrostatic Analyser, facing the Sun, measured positive ions and electrons, whilst the backward-looking Electron Spectrometer measured electrons only. A further experiment, known as the Charged Particle experiment, measured charged particles originating from the Sun and was designed to look for the possible magnetic tail associated with Mercury. During the cruise stage, measurements were made on cosmic rays with the ability of identifying the source as solar or galactic.

Although, to the layman, the television system and its resulting photographs were the most spectacular, the pictures obtained were just one link in the chain of the understanding of the conditions existing on Venus and Mercury. The system consisted of two catadioptric Cassegrainian telescopes, with a system of eight filters. An auxiliary optical system linked to the telescope via a mirror on the filter wheel allowed the probe to take both wide-angle and narrow-angle photographs. The telephoto system had a

focal length of 1,500 mm and a field of view of  $\frac{1}{2}^\circ$ , whilst the wide-angle system provided a field of view of  $11^\circ$ – $14^\circ$ . Exposure times could be varied from three milliseconds to 12 seconds, and a picture could be taken every 42 seconds, each picture consisting of 700 scan lines with 832 elements in each line. In common with all spacecraft, Mariner carried an experiment to measure magnetic fields in the near planetary regions and interplanetary space. There were two magnetometers on board, one mounted at the end of a 180-cm long boom and the other near to the body of the spacecraft; this latter one was used to give a measure of the disturbance to the magnetic field generated by the spacecraft itself.

The celestial mechanics experiment, not needing any special equipment, involved the studying of the behaviour of the radio signals during the fly-by of the planet, and in particular at the moment of disappearance and reappearance when the probe was occulted by the planet. The times of cut-off and reappearance gave precise information on the diameter of the planet, whilst an examination of the behaviour of the signals just prior to cut-off gave information on pressure, temperature and other properties of the atmosphere. Because of the extraordinary thick atmosphere of Venus, the large refraction or bending of the radio waves required a compensating movement of the antennæ. This allowed studies of the conditions existing lower in the atmosphere than would have otherwise been possible.

### **The Journey to Venus**

Soon after the start of the journey to the planet, trouble occurred in the television camera system. The heater system for the camera failed to come into operation on command. It was thought that the low temperatures would do irreparable damage to the television system, and it was decided to leave the vidicon tubes switched on so that the heat generated would prevent the temperature from falling too low. This was rather worrying, because it was felt at the time that the cameras might fail, due to the limited lifetime of the tubes, long before the probe had reached Mercury. The trouble was cured later, and the cameras worked perfectly. A

## MARINER 10 TO VENUS AND MERCURY

partial failure in the plasma-science experiment was caused by one of the covers of the instrument failing to open fully. This cover was designed to be blown free of the spacecraft soon after launch. The partial loss of information did not turn out to be too serious, and much useful information was sent back. On 25 December, an intermittent fault developed in the radio equipment used for transmitting information back to Earth. It did not affect transmissions during Venus encounter, but the reduced ability affected the Mercury fly-by. Certain planned pictures of Venus could not be taken because the camera platform would only turn through an angle of  $107^\circ$  instead of the designed  $122^\circ$ .

Another nerve-racking event occurred when the probe was about 21 million kilometres from the Earth. The spacecraft suddenly switched from the primary power, using solar panels, to the back-up battery supply. Unfortunately there was no way of switching back, but N.A.S.A. felt that it would be most unlikely for a second fault to occur, and at the time expressed confidence that everything would work out all right. In fact this was the case.

The use of the interplanetary journeys for studies of the solar system are usually limited to measuring the properties existing in the immediate neighbourhood of the probe. However, with *Mariner 10*, the opportunity was used to observe Comet Kohoutek. The main lines of study involved the ultra-violet spectrometer and on 17 January the experimenters were able to identify the hydrogen halo of the comet to a distance of  $12^\circ$  from the nucleus in the anti-solar direction.

### Venus Encounter

The track of the fly-by of Venus was governed primarily by the requirements for the near approach to Mercury. It permitted a very detailed study of the upper clouds as well as providing a more accurate value for the radius and mass of the planet. It passed Venus at the planned distance on 5 February. Forty minutes before closest approach, the cameras came into operation; and before photography ceased, on 13 February, 3,000 pictures of the planet had been transmitted back to Earth. During the 21

minutes when the probe was occulted by the planet, the pictures were tape recorded.

For many years the planet was a completely unknown body, the featureless clouds seen from the surface of the Earth providing little reliable information. Since 1962, when *Mariner 2* flew past the planet, several Soviet spacecraft have studied the atmosphere and some have made soft landings on a solid surface. Radar observations have shown that the surface contains large shallow craters, and earth-based observations in ultra-violet and infra-red have indicated that the clouds were very fast moving, possibly with a rotational period of about 4 days compared with the solid surface rotational period of 243 days. In addition, there appeared to be a fairly rapid pulsation of about 4 days in the height of the top of the clouds. Data from these earlier probes showed that the atmosphere consisted mainly of carbon dioxide with surface pressures of about 100 Earth atmospheres and a temperature of about 400°C at the surface. In the lower regions of the atmosphere the Russians have reported large quantities of water. It was this strange world that *Mariner 10* was sent to investigate. Would its instruments confirm or reject any of the above accepted facts?

Studies of the limb of the planet with a resolution of about 200 metres showed quite distinctly several haze layers lying above the main cloud layer. The cusps, easily seen from earth-based observatories, were observed and shown to be caused by the bending of sunlight due to refraction. The photographs showed them to be completely featureless. The infra-red radiometer provided data which showed that the atmosphere was completely opaque, but there were variations in the limb darkening curve which suggested the existence of variations on the same scale as the markings seen in ultra-violet light.

In the atmosphere there are four distinct temperature inversions at heights between 55 and 65 km. Evidence was found for an ionosphere consisting of two layers (140 and 120 km) on the night side but just one peak value at 145 km on the day side.

The photographs in ultra-violet light confirmed the existence of the markings seen from the Earth. They provided a detailed

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pattern of the motion of these clouds with a resolution of about 15 km. Whereas the tropical regions showed rising and descending cells in large numbers, the temperate and polar regions showed long streaks similar to cirrus cloud. The clouds appear to spiral from the equator to the poles. The rapid rotational period of 4 days was confirmed.

Analysis of the atmosphere showed that the upper regions contained hydrogen and helium and a significant amount of oxygen, but there was little evidence of deuterium. As indicated by the earlier probes, Venus does not possess a magnetic field, and so the solar wind can penetrate the atmosphere.

Preliminary results from the S- and X-band transmissions have indicated that the mass of the planet is only slightly less than that obtained from similar experiments on earlier probes, the ratio of the masses of the Sun and Venus being 408,524 against the previously accepted figure of 408,520.

### Mercury Encounter

Mercury is a very difficult planet to observe, due principally to the facts that it is relatively small and that it is never very far from the Sun. The maximum angle it can be from the Sun is about  $27^\circ$ , and the time spent at this distance may amount to only a few days each year. Visual observations of the surface can be made only at times near to elongation, and this has prevented systematic study of the surface for a long period of time. Up to 1965, it was always thought that the planet had a captured rotational period of 88 days, but radar studies showed that the correct period to be 58.6 days. Faint markings have been observed on the planet, and maps have been drawn up, giving a resolution comparable with that achieved when looking at the Moon through light cloud. The terminator had been observed to be irregular in shape, and the planet had an albedo of 0.07, a value similar to that of the Moon. It was therefore thought that Mercury and the Moon could be quite similar, an idea supported by the results from radar studies of the Mercurian surface. These studies suggested a rough and heavily cratered surface. Earth-based observations gave surface

temperatures ranging from  $360^{\circ}\text{C}$  on the sunlit side falling to  $-160^{\circ}\text{C}$  at night. This large range in temperature, together with the fact that its nearness to the Sun and its size prevented the formation of an appreciable atmosphere, seemed to indicate very hostile conditions existing on the surface. Little was known of the existence, if any, of a magnetic field and so virtually nothing could be said of the effect of the solar wind in that region.

It was with this relatively scanty knowledge about the planet that man's first probe approached Mercury; hopes were very high for a successful fly-by and for answers to some of the questions that had been asked for a very long time. These hopes were justified, for on 29 March the spacecraft flew past the planet at a distance of about 700 km with all the equipment working well. About 2,300 photographs were taken, those taken near to the closest approach giving a resolution of about 100 metres. The probe approached the planet from slightly below the orbital plane of Mercury, the cameras concentrating on the Mercurian 'afternoon' in the southern hemisphere. On crossing the evening terminator, the cameras were deactivated until the morning terminator came into view, when another series of photographs were taken, this time mostly of the northern hemisphere. Craters turned out to be the dominant feature of the surface, the density varying from one area to another. The craters seemed to have the same characteristics as their lunar counterparts, suggesting a similar origin and erosion processes. They did appear to be shallower than lunar craters of the same size. Further, the secondary craters were found to be positioned closer to the primary, as would be expected with the larger gravitational field existing on Mercury. The circular plains identified in the photographs are similar to the circular lunar maria and in one case a very strong resemblance to the lunar Orientale Basin. Of great interest were the identification of large scarps, unknown on the Moon, attaining heights of 3 km and extending for well over 500 km, cutting across large craters. Rills, a common feature on the Moon, are not so numerous.

A bright crater identified on photographs taken when the probe was several hundred thousand kilometres away from the planet

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was subsequently resolved into a prominent rayed crater. This feature has been named Kuiper in honour of the well-known planetary astronomer Gerard P. Kuiper, who died in December 1973. He was a leading member of the team responsible for American planetary space probes.

The infra-red radiometer recorded a steady decline in surface temperature from local sunset to midnight. In the mid-afternoon the temperature was about  $180^{\circ}\text{C}$ . As the terminator was crossed the temperature fell rapidly to  $-120^{\circ}\text{C}$  and then more slowly to  $-170^{\circ}\text{C}$ . The scan readings were not smooth, indicating irregularities in the surface. The low night-side temperature and the rapid fall as the terminator was crossed indicates a surface material similar to that on the Moon.

The plasma-science experiment provided overwhelming evidence for a strong interaction between Mercury and the solar wind, suggesting a fairly strong magnetic field, a result supported by the magnetometer experiment. A field strength of about 1 per cent of the Earth's field is given. There is doubt at the moment as to the origin of this field. It could be a genuine planetary field, but the possibility of a field induced by the solar wind interaction has not at the moment been ruled out.

The ultra-violet data has shown that Mercury does in fact have an exceedingly thin atmosphere consisting mainly of helium, the surface pressure being in the region of  $2 \times 10^{-9}$  millibars, a vacuum by terrestrial standards.

The analysis of the radio tracking data gave the Sun/Mercury mass ratio of 6,023,600, a value in agreement with the recent radar work but higher than the previously accepted figure of 6,000,000. The calculated value for the equatorial diameter is in agreement with that previously accepted. This confirms the mean density of 5.44.

The probe carried on in its orbit round the Sun and then passed within 55,000 km of Mercury for a second time on 21 September. On this occasion over 500 high quality photographs were taken, some of areas not seen during the earlier pass. This increased the area usefully photographed from 25 to 37 per cent. Only the

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television system and the ultra-violet scanner were operated during this second pass. A third pass was made in March 1975.

No matter what way one looks at it, the *Mariner 10* flight was a tremendous success. All of the inner planets have now been put under scrutiny of Mariner space probes and the results obtained have given us a far more accurate picture of the near-Sun region than was ever possible from just Earth-based observations. The next Mariner will fly to Jupiter and Saturn. One thing is certain, and that is there will be many surprises!

# **Titan: a Satellite with a Recycled Atmosphere?**

G. E. HUNT

## **Introduction**

Titan, with a radius of  $2,500 \pm 250$  km is the largest satellite of the Saturn family, and one of the largest satellites of the Solar System, comparable in size to the terrestrial planets Mercury and Mars. Situated in the outer portions of our solar system, Titan never comes closer to us than 8 AU (1,500 mkm approximately) and at that distance its angular diameter is less than 0.8 sec of arc which is just clearly resolvable with modern large telescopes under excellent seeing conditions. Even at these distances, planetary observations have shown Titan to be one of the most interesting bodies in the Solar System.

## **Atmospheric Composition**

Titan has an atmosphere. It is not tenuous like that possessed by Io, the only other satellite in the Solar System known to possess an atmosphere. The Titan atmosphere is massive. Large enough to be detected spectroscopically from the Earth, and these observations suggest the Titan atmosphere is certainly greater than that on Mars and may indeed be as large as the terrestrial atmosphere.

In 1908, José Comas Solà, observing in Barcelona had remarked on the dark lines of Titan and transient light patches on its tiny disk. Markings were again recorded in the 1940s by Lyot and his associates at the Pic du Midi Observatory in the French Pyrenees. Though these variations in the features seen on the Titan disk could be due to a period of rotation smaller than the period of revolution, they are more likely due to an overlying atmosphere

containing clouds. The limb darkening, which is apparently always observed, may be taken as an indication of an atmosphere.

Thirty years ago Kuiper laid the foundation stone for Titanian atmospheric studies by detecting, unambiguously, the presence of methane. Hydrogen has now been detected in the satellite's atmosphere and while it is common in the outer Solar System, its prominence on such a small body as Titan is surprising. It is interesting that the amount of hydrogen and methane observed on Titan alone would produce a pressure of 20–70 mbar, depending on the proportions, which is much in excess of the surface pressure of Mars!

The study of the composition of a planetary interior can provide important clues to possible constituents of an atmosphere when further observational information is not available. In Table 1 we have presented the physical characteristics of Titan. It is a regular satellite rotating in a prograde manner about Saturn. The density of Titan is  $2\text{ g cm}^{-3}$ , which is twice the value for water, so that it falls in the class of icy satellites.

*TABLE 1*  
PROPERTIES OF THE EARTH AND TITAN

| <i>Parameters</i>               | <i>Earth</i>                                | <i>Titan</i>                                |
|---------------------------------|---------------------------------------------|---------------------------------------------|
| Mean Distance from Sun          | 1 AU                                        | 9.546 AU                                    |
| Mass                            | $5.97 \times 10^{24} \text{ kg}$            | $(1.37 \pm 0.02) \times 10^{23} \text{ kg}$ |
| Equatorial Radius               | 6378.16 km                                  | $2500 \pm 250 \text{ km}$                   |
| Mean Density                    | $5.517 \text{ g.cm}^{-3}$                   | $2.1 \pm 0.6 \text{ g.cm}^{-3}$             |
| Equatorial Surface Gravity      | $978 \text{ cm.sec}^{-2}$                   | $146 \pm 30 \text{ cm.sec}^{-2}$            |
| Rotation Period                 | $23^{\text{h}} 56^{\text{m}} 04^{\text{s}}$ | 15.95 DAYS                                  |
| Inclination of Equator to Orbit | $23^{\circ} 45'$                            | $\sim 27^{\circ}$                           |
| Albedo                          | 35 per cent                                 | $\sim 26$ per cent                          |
| Cloud Cover                     | 50 per cent                                 | $\sim 100$ per cent (??)                    |

Titan is one of the three largest satellites in the Solar System. The

## TITAN: A SATELLITE WITH A RECYCLED ATMOSPHERE?

others are Ganymede and Callisto of the Jovian system, and all three are of comparable radius. By mass it is third after Ganymede and Triton, the largest satellite of Neptune, while the density of Titan is less than that of Triton, the Moon and two other large satellites of Jupiter, Io, and Europa. Though Ganymede is comparable to Titan in size, mass, and density, there is no conclusive evidence of an atmosphere on this body. Io has a tenuous atmosphere which is thought to be due to the vigorous interaction between the planet and the extensive Jovian magnetosphere where it resides. This comparison between Titan and satellites with comparable physical properties emphasizes the uniqueness of the planetary body.

If we propose that the planetary satellites were formed by accretion from the condensed form of the solar nebula, then the composition of the Titanian interior may be composed of approximately 60 per cent of a solution of  $\text{NH}_3$  in  $\text{H}_2\text{O}$ , 5 per cent of  $\text{CH}_4$  with the remainder made up of the substances which condense at high temperatures such as the oxides of magnesium, iron, and silicon. If the methane were fully outgassed its pressure would be 1 k.bar. This model assumes that melting took place early in Titan's history from heating by radioactive decay, while the present structure is envisaged as a thin ice crust floating on a liquid  $\text{H}_2\text{O}-\text{NH}_3$  mantle surrounding a core of hydrous silicates and oxides. From this model the observed hydrogen must result from the dissociation of  $\text{NH}_3$  or  $\text{CH}_4$ , since the temperatures are too low for  $\text{H}_2\text{O}$ . Nitrogen, which cannot be detected spectroscopically, is also a likely atmospheric constituent formed in this way. Also we can expect the formation of the hydrocarbon products  $\text{C}_2\text{H}_6$ ,  $\text{C}_2\text{H}_4$ ,  $\text{C}_2\text{H}_2$  and methylamine  $\text{CH}_3\text{NH}_2$ . Ethane and acetylene have already been detected in the atmospheres of Jupiter and Saturn. Hydrocarbon structures of this type also play an essential role in the complex atmospheric chemistry of the planetary bodies in the outer system which result in the exotic colours we observe. Titan, for example, appears as an orange colour, but we are still ignorant of the origin of this colour.

The concept of formation of the satellites of the major planets

by the accretion of planetesimals reduces pure hydrogen to a minor role. But the parent planets contain large quantities of hydrogen, although not necessarily in solar proportions. One may resolve these contrary circumstances by considering the planets as having contracted in massive form from the solar nebula, rather than having accreted. But it is not clear why the major planets should have formed differently. It is more likely that they were accreted; and once having reached sufficient mass, swept up all nearby volatiles to acquire hydrogen. Furthermore, it is also possible that hydrogen may have been in the original satellite structure, for if the Sun had been partially shrouded by dust at these early stages, accretion may have occurred at colder temperatures than presently assumed. Then Titan may have had the full complex of gases,  $H_2$ , He and the important noble gases Ne and Ar.

### **Clouds and Aerosols**

There is evidence for scattering particles in the Titan atmosphere. This has come from studies of the linear polarization of the light reflected by Titan which shows a positive gradient with increasing phase angle (the angle between the Sun, Titan, and the observer) up to the maximum viewing angle from the Earth of  $6^\circ$ . Surface material found on the Moon, Mercury, Mars, and the Earth is negatively polarized over this angular range. This has led to the suggestion that the clouds are opaque and obscure the ground. But we should not assume that the surfaces of the terrestrial planets are typical of all planetary bodies. A surface covered by a glassy or tarry layer of photolysis products, which is similar to some earlier suggestions for the Venus surface, has been postulated for Titan.

Such a surface is indeed possible and would be caused by the atmosphere, built up by outgassing from the interior, and the lower boundary not being in equilibrium. Certainly the polarization properties of this type of surface are unknown. So we must wait until 1981 for the first close-up pictures of the satellite from the Mariner Jupiter/Saturn Spacecraft to know whether the Titan surface is visible or obscured by clouds. Then we may also under-

## **TITAN: A SATELLITE WITH A RECYCLED ATMOSPHERE?**

stand the transient features observed on the Titan disk by early observers.

The composition of the clouds is at present unknown. They are probably responsible for the satellite's remarkable orange colour, a feature which it shares with Io and the equatorial region of Saturn. There is also considerable similarity between the reflection spectrum at ultra-violet and visible wavelengths of Titan and Saturn, which suggests a similar composition for the high clouds of both objects. In fact, all the major planets show a qualitative drop in the albedo at wavelengths towards the ultra-violet portion of the spectrum, which may be accounted for by an absorbing haze layer such as that found in the Jovian stratosphere by the Pioneer 10 occultation experiment. Titan differs from the major planets in its lower albedo and the absence of Rayleigh scattering at short wavelengths. Consequently, the haze layer may be very high in the Titan atmosphere. Since pure  $\text{CH}_4$  clouds do not absorb strongly in the ultra-violet, and it may also be too warm for methane condensation, the haze is likely to consist of hydrocarbon products formed from photolysis reactions in the atmosphere. The absorption of sunlight by hazes of this type provides a substantial energy source for the upper atmosphere, and may lead to a temperature inversion at these altitudes, as has been shown by the Pioneer 10 observations of Jupiter.

### **Atmospheric structure**

The temperature structure of the Titan atmosphere is a controversial topic, and we still have not reached a consensus of opinion from the available observational data. A rapidly rotating, thermally non-conducting body at Titan's distance from the Sun would have an equilibrium temperature of  $90^\circ\text{K}$ . If it were slowly rotating, the corresponding value would be  $108^\circ\text{K}$ . Observations indicate that the value is as high as  $150^\circ\text{K}$ . The higher measured temperatures are indicative of a greenhouse effect where the solar radiation penetrates to the satellite surface, but the thermal radiation (heat) is trapped by the atmosphere, opacity thereby heating the atmosphere. Various models have been developed to explain the

observations and pressures of anywhere between 0.1 to 1.0 atm or more are required. The most favourable analysis concluded that a greenhouse may be maintained by equal amounts of hydrogen and methane, which give rise to a minimum surface pressure of 440 mb and a temperature of  $\sim 155^{\circ}\text{K}$ . Although helium has entered into the analysis, it is difficult to accept, since this gas can rapidly escape from the atmosphere.

The alternative model is based upon a warm stratosphere constructed from the knowledge of the low ultra-violet albedo which results from layers of photochemical aerosols or dust high in the atmosphere absorbing the available solar energy. This model places the surface temperature at about  $80^{\circ}\text{K}$ , but the radiating layer could be at some height in the atmosphere for a greenhouse model.

This problem and the two models used to interpret the data are again similar to the problem of explaining the apparent high surface temperature of Venus before the Venera landings. But a high surface temperature seems unlikely for Titan. The brightness temperature at 3.7 cm is  $115 \pm 40^{\circ}\text{K}$ , which rules out a hot surface unless it is obscured by strong atmospheric absorptions.

The surface of Titan may therefore be cold, covered with a layer of photochemical products and their polymers, which are usually reddish brown in colour and may therefore be related to Titan's unusual colour. The critical observations to resolve the present controversy of the thermal structure need to be made at infra-red wavelengths in the neighbourhood of  $17\mu$ , and they appear to be technically feasible today.

The theories which need clouds, aerosols, or dust layers require a closer inspection of Titan's meteorology. It is a slowly rotating planetary body with an orbital period of 15.95 days and thought to be synchronous with Saturn. The Titan circulation will represent an intermediate case between the baroclinic circulation typical of the mid-latitudes of the Earth and Mars and the symmetric Venus weather patterns. Certainly we should like to know more about the wind field, and whether it is capable of mixing and suspending the dust particles and particulate matter as the theories

## TITAN: A SATELLITE WITH A RECYCLED ATMOSPHERE?

require. If clouds are present, then there must be convective processes, and the variation in the appearance to visual observations probably implies precipitation/evaporation processes. Titan is another body in the Solar System quite different from other planetary atmospheres where we may test meteorological theories and analyses. Vital information on the Titan atmospheric motions will come from the observations made during the Mariner Jupiter/Saturn fly-by in 1981. We can be assured that quite unexpected results are in store from this first close-up look.

### Atmospheric Recycling

How does Titan manage to retain an atmosphere?

For a pure  $H_2$  atmosphere at a temperature of  $100^\circ K$  the atmosphere would escape in only 4 hours! If a heavier gas is present, this retards the loss by its diffusion through the lower atmosphere. The escape fluxes of  $H_2$  have been estimated to be between  $10^{11}$  and  $10^{12} \text{ cm}^{-2}\text{s}^{-1}$  when the heavier gas is either  $N_2$  or  $CH_4$ . Above the region of mixing, the escaping hydrogen will form a corona extending to several Titan radii.

What is the fate of the escaping  $H_2$ ? The escaping atoms will lack the velocity to escape from Saturn, and consequently they will be distributed into a toroidal volume around the orbit of Titan until they are recaptured by the satellite. The lifetime of an atom of hydrogen in the torus is about 6 years, which is approximately 140 Titanian orbital periods. Consequently, the hydrogen atoms will not be lost completely but will be swept up by the planet as it orbits Saturn.

The toroid is a fascinating object in itself, and the significant recycling back to Titan greatly eases the problem of finding an adequate source of  $H_2$  for Titan's atmosphere. The precise characteristics of the ring are presently unknown, but estimates place the density of the atoms at  $10^{10} \text{ cm}^{-3}$  and suggest that its width in the equatorial plane is  $20S_R$  (Saturn radii) with thickness  $10S_R$ . A neutral gas ring of this type associated with the Io orbit has been found around Jupiter by the ultra-violet photometer on Pioneer 10.

### **Conclusion**

Titan is a fascinating object for future planetary explorations. It possesses a substantial atmosphere, possibly maintained by an efficient recycling process. Aerosols formed by photochemical reactions are present in the atmosphere, giving rise to the orange coloration of the satellite, and playing a fundamental role in the transfer of radiant energy and motions in the satellite's atmosphere. They may even obscure the surface.

The photochemistry of Titan is complex. The photolysis of methane and possibly ammonia will result in numerous organic compounds, and many of them may precipitate to the surface which may then be covered with a thick layer of tar. If the surface pressure and temperature are high enough, an ocean of liquid methane is possible. The surface of Titan may be the best place in the Solar System for the investigating of prebiotic organic chemistry.

The question as to why Titan is unique is difficult to answer, since much more information about this satellite is needed. Satellites of comparable size closer to the Sun, such as the Galilean satellites, are apparently too close to hold anything but a tenuous atmosphere. Those further than Titan may be too cold to possess much of an atmosphere. It will be interesting for example to determine whether Triton, or even Pluto, has a hydrogen atmosphere since they are likely to be too cold for much gaseous methane. We must now ask ourselves: did the other satellites of Saturn form differently from Titan? Did Titan form differently or similarly to Saturn, except for the subsequent differentiation caused by size? Unravelling the mysteries of Titan may therefore have considerable cosmological significance.

To understand fully the physics, chemistry, and meteorology of the Titan atmosphere and environment, and to examine the surface of the satellite, will require space probes. The International UV Explorer satellite destined to be launched in 1976 may be able to observe Titan at ultra-violet wavelengths and identify constituents. In 1981 the first close-up observations of Titan will be made from the Mariner Jupiter/Saturn fly-by mission, when

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a battery of instruments will study the satellite at wavelengths from the ultra-violets to the microwave portion of the spectrum. But it may finally require an atmospheric entry probe mission to answer the fundamental and exciting problems associated with this enigmatic planetary body.

## **Prominence Observations for the Amateur, Using a narrow Band Filter**

RAMON LANE

At one time, a device for prominence observation was thought beyond the capability of the ordinary amateur but in recent years scientific progress has resulted in the production of H-Alpha filters, within the budget of the amateur.

Before I start on the description of my prominence attachment I will say a little on the type of filter used. In order to see prominences the filter should be of narrow band with a maximum transmission at 6,563 Ångströms, that being the position of the prominent H-Alpha line in the solar spectrum, the band pass should be less than 30 Å, especially in Britain. The filter that I use is an all-dielectric type 2 inches in diameter with a band pass of about 10 Å. This type of filter at present is about £70 for a 30 Å filter. Much narrower band filters are available, some as narrow as 0.1 Ångström, but the cost of these filters runs into several hundred pounds. A 1 Å filter one inch in diameter would cost about £250 to £400 depending on quality.

Now to the design of the prominence attachment.

I have mounted all of the optics within plastic tubes, obtained as scrap from a plumber. The cone stop, field lens, scatter stop and projection lens are all mounted within 1½ in. tube; a 2½ in. tube holds the H-Alpha filter, star diagonal, and eyepiece. This larger tube slides over the small tube that is held in place by a number of spacing rings. The field and projection lenses were taken from a cheap pair of 7 × 30 binoculars. The focusing mount is a 35 mm camera extension bellows, which can take a camera when the eyepiece and diagonal are removed; also a camera

## PROMINENCE OBSERVATIONS FOR THE AMATEUR

bellows is lighter than a brass focusing mount and it serves the same purpose. Provision has been made to adjust the tilt of the filter as temperature changes and Doppler shift can affect the transmission of the H-Alpha wavelength. The very narrow band filters do not require as many optical components and in some cases the filter can be mounted in front of the object glass. Also with the narrow band filters one can see surface details such as flares, plage, filaments, and other H-Alpha phenomena, but prominences are a little less bright.

Photography of prominences is quite easy both in black and white, and colour. As seen from Figure 1, I use an occulting cone to block out the disk of the Sun, even with the very narrow band

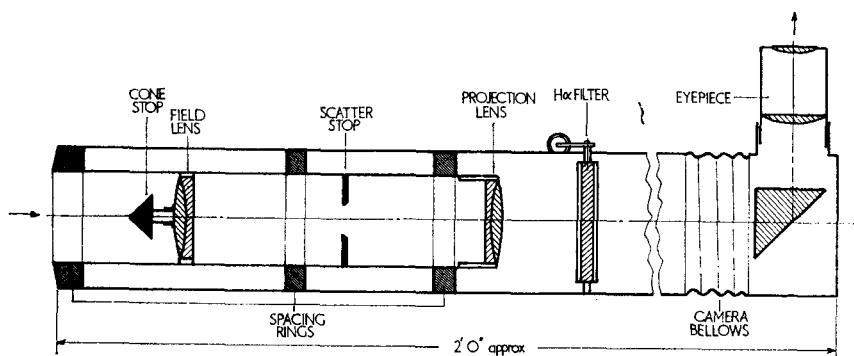


Figure 1.

filters I would still recommend a stop as the brightness of the prominences and disk are vastly different. Film speeds published by the film manufacturers are generally no good for H-Alpha photography, sometimes a film rated at A.S.A. 400 will not record any image at all while a one of A.S.A. 125 will record a very dense image with the same exposure. I use AGFA 1SS 35 mm film with single lens reflex camera, the exposure being 1/15 of a second. Using the same eyepiece and camera with colour film the exposure can be as short as 1/500 of a second. Ciné films can also be made of prominences using reflex viewing movie cameras. One simply

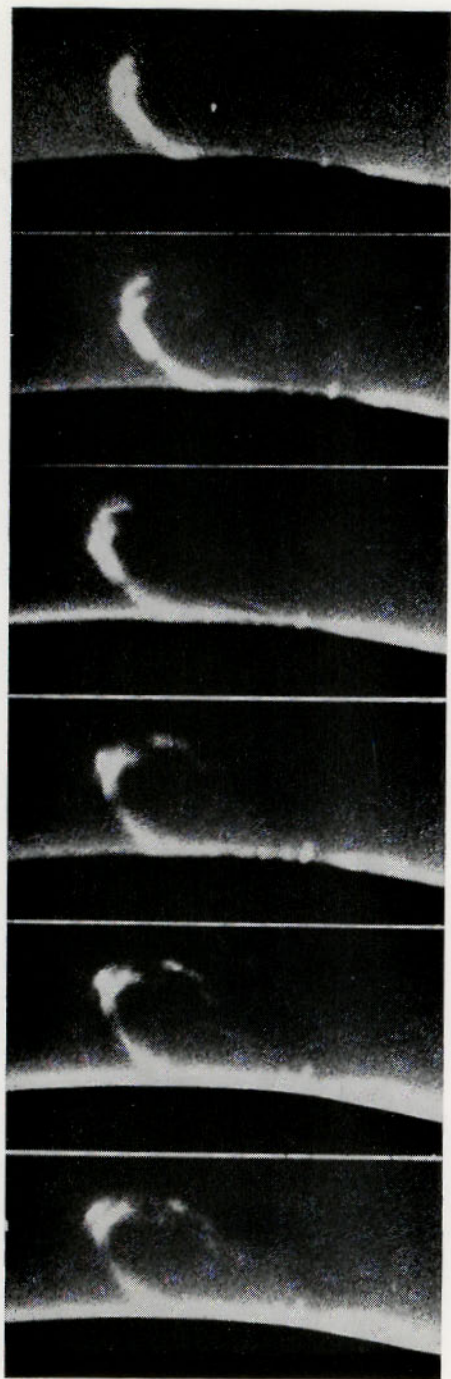
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clamps the movie camera on to the eyepiece of the telescope and views through the camera viewfinder. It helps if the viewfinder has a rubber eye cap to exclude stray light from the eye. The camera lens should be used at full aperture and the number of frames per minute should be adjusted, if possible, to give a time lapse affect.

### Points to note:

- (A) *Never* look directly at the Sun without the filter or a solar diagonal fitted. DO NOT RISK YOUR EYESIGHT.
- (B) *Do not* fit the camera on to the telescope without first mounting the filter. The heat from the Sun could ruin the camera.
- (C) Make sure that the filter or camera attachment is securely fitted and that the telescope is correctly counter-balanced.

*Figure 2.* Time lapse: one frame at half-minute intervals.



## The BL Lacertæ Objects

D. A. ALLEN

Since radio astronomy began in what now seems very far-off days, one or two of its practitioners have become somewhat possessed with the concept of *radio stars* and have pursued them as they might the seven cities of gold. Because one object – the Sun – was early discovered to be a normal star emitting radio waves, other examples were thought to be inevitable. Yet the earliest surveys revealed all strong radio sources to be either galactic nebulae, like the Crab and the Orion nebulae, or galaxies. With confidence that stellar radio sources would emerge if deeper surveys were made, larger radio telescopes were used to detect progressively fainter radio sources until at last some began to be identified with star-like objects. But even to this day none of these identifications are ordinary stars like the sun. The list comprises the following:

1. Flare stars – faint dwarf stars which emit sudden outbursts of energy brightening for a few minutes by several magnitudes and becoming at that time detectable by radio telescopes.
2. A number of stars with emission lines in their spectra. These stars are surrounded by clouds of gas, and it is the gas which produces the emission lines and the radio waves. These objects are, in effect, miniature Orion nebulae. The first of them to be discovered was the blue companion to Antares.
3. Some binaries which again have gas clouds, this time lying between the stars. Algol is the best-known example.
4. Pulsars, which by no stretch of the imagination can be described as ordinary stars. They seem to be one of the last

phases in the life of a star, one in which the energy cannot escape in the usual way and has to leak from the object in a narrow lighthouse beam which sweeps across the Earth with every revolution of the star.

5. The quasi-stellar objects, *quasars*. With these objects, which certainly look like stars through large telescopes and on photographs, we leave the realms of our own galaxy and venture into the vast stretches of intergalactic space. Quasars are probably the most distant and the most luminous objects known, and it is only their great distance which makes them appear stellar. Quasars are one of the unsolved mysteries of astronomy – we do not know for certain how bright or distant they are, what causes their great luminosity, or why they seem to have thrown off narrow shells of gas at very high velocities. To quasars I shall return later in this article.
6. The BL Lacertæ objects.

### Variable Stars and Radio Sources

It is some years now since Michael Penston identified the radio source 3C 120 with the little-known variable star BW Tauri. The third Cambridge radio survey had not long been published and both optical and radio astronomers were seeking identifications for the several hundred sources it contained. BW Tauri came as a surprise, for no other variable star was a known radio source. Photographs and spectra of it were taken, and BW Tau was shown not to be a star at all, but a galaxy. More precisely it is a Seyfert galaxy. These were described by Simon Mitton in the 1973 Yearbook, and it is necessary at this juncture only to remind readers that Seyfert galaxies have very small and extremely bright nuclei in which some strange process occurs that produces a lot more energy at optical, infra-red and radio wavelengths than in the nuclei of normal galaxies. In the case of BW Tau, which is quite faint, only the nucleus had been seen by the variable star observers; the rest of the galaxy required long exposure photographs to reveal it. Like BW Tau most Seyfert galaxies are irregular variables of small amplitude. So, for that matter, are many quasars.

Only with a considerable increase in the number of known radio sources was it possible to find more which were already classed as variable stars. Many radio catalogues were being compiled at the time Penston made his identification, and it was not long before more such identifications were made. Three more, in fact: W Comæ Berenices, BL Lacertæ and AP Libræ. Of these BL Lac was the first.

It was Schmidt who in 1968 identified BL Lac with a weak entry in a radio source catalogue made at the Vermillion River Observatory in Illinois, U.S.A. Both the radio and optical brightnesses were found to fluctuate wildly with considerable amplitude and no hint of a regular period, and this fact strengthened the identification. The other two objects are also irregular variables. All three appeared stellar at first sight.

### **Spectra of BL Lac**

Next after the telescope itself, the optical astronomer's most important tool is the spectroscope. With it he can study the chemical composition, temperature, density, mass, etc., of galactic objects and the red shift (and hence, we believe, distance) and nature of extragalactic sources. It was thus with much interest that spectroscopes were turned to BL Lac. Would it prove to be a galactic star of some sort, or an extragalactic object such as a quasar or Seyfert galaxy? The answer was incredible: BL Lac showed absolutely no spectral features. The spectroscopes revealed merely a continuum of light from the ultra-violet to the far red with not a single bright or dark Fraunhofer line. Suddenly an object had been found for which the spectroscope could tell us nothing. Astronomers felt like the detective first confronted by a crime for which gloves had been worn and no fingerprints existed.

BL Lac had won the first round. Baffled, the world's astronomers collected their thoughts and sought other, less direct means of learning about this object. Indirect and rather esoteric arguments were produced which alleged to demonstrate that BL Lac must be extragalactic. And while the arguments were being weighed, AP Lib, W Com and two others were discovered to share

the same features. The last two were objects which had not been spotted by variable star observers and are known only by their numbers in the Ohio radio survey: OJ 287 and ON 325. The last few years have witnessed the discovery of more BL Lac objects, but they are all faint and not well studied. It is the first five which will always be remembered as *the* BL Lac objects.

### **The Salient Features**

If the spectroscope proves useless, what can one do to learn about an object? The obvious things are to photograph it to search for some structure to it, and to measure its brightness and brightness variations at every available wavelength. These things were quickly done, and the following features became recognized and accepted as the hallmark of the BL Lac objects:

The optical spectrum is featureless.

The radio spectrum is that of synchrotron emission – like radio galaxies and quasars.

In the ultra-violet and infra-red the objects are unusually bright; indeed the BL Lac objects emit most of their energy in the infra-red at a wavelength about 20 times that of visible light.

At all wavelengths they vary in brightness by up to a factor of ten; variations occur on a day-to-day time-scale, and possibly even from hour to hour.

Although basically stellar, when near minimum light a fuzzy edge can be seen, especially in BL Lac itself, as though some very bright variable source is superimposed on a faint nebula.

An attempt was made to coin the term 'Lacertids' to describe these objects. This, however, only causes confusion with meteor showers and I, in common with most astronomers, will promote calling them BL Lac objects.

### **The Red Shift of BL Lac**

A bright source superimposed on a faint nebula . . . Now that offers a possibility. Suppose we blot out the central bright source just as a visual observer of Venus uses an occulting bar to hide the sunlit part of the planet when he searches for the Ashen Light: could we then get a spectrum of the nebula around it? An experi-

ment worth performing, surely. An experiment which, indeed, was performed, by Bev Oke and Jim Gunn using the 200-inch telescope on Palomar Mountain. Oke and Gunn found that the fuzz around BL Lac *seems* to have the spectrum of an elliptical galaxy. I stress the word 'seems' because this really was a very difficult experiment to perform, and the results are not as convincing as one would like. Indeed, a second group has performed the same experiment and claims that there are no spectral features in the fuzz either. However, we will use the results of Oke and Gunn, since they at least seem to give reasonable answers to the questions we raise. The red shift of the galaxy they found to be 0.07, which means that BL Lac is receding from us at 20,000 km/second. At that rate it would cross the Solar System in a few hours. And if Hubble's law applies we can compute the distance to be one thousand million light years, a distance greater than that of any galaxy in the NGC or IC lists. Yet BL Lac can become as bright as the 12th magnitude; it must therefore be a very luminous object. When we work out its total luminosity, including ultra-violet, visible, radio and infra-red radiation, we find it to be comparable to the faintest quasars, and these I have already noted to be the most luminous objects known. Presumably the other BL Lac objects are similar.

### **The Infra-red Radiation**

Many extragalactic objects are radiating particularly strongly in the infra-red region of the spectrum. In most cases we attribute the infra-red emission to clouds of dust which absorb starlight at visible wavelengths, warm up to about room temperature and radiate the energy in the infra-red. If dust produces the infra-red emission in the BL Lac objects, too, as seems likely, there must be an impressive amount of it. Moreover, we can derive the size of the dust cloud by a well-established argument which runs as follows:

When we measure the infra-red signal from a dust cloud, we simultaneously record the nearest and most distant portions of that cloud. If a change occurs in the ambient conditions of the dust so that its temperature and the energy it emits are altered, we see first the change in the nearest dust and only after some time

the change in the more distant material. The delay equals the time taken by radiation to cross the dust cloud. Any variation at the object appears to us spread out in time by this delay. Now if BL Lac is observed to vary in one day the size of the dust cloud cannot exceed one light day. And if hour-by-hour variations are confirmed at infra-red wavelengths the cloud must be correspondingly smaller.

So at the centre of BL Lac there seems to be a cloud of dust not a great deal larger than the Solar System which is powered by a source many million million times as bright as the Sun. Quite apart from the question of what sort of object can produce so much energy in so small a space is the problem that if such a source existed, it would totally evaporate all the dust. We thus find ourselves in an inconsistency out of which all paths seem extremely contrived. We cannot envisage a very satisfactory explanation of the infra-red radiation which does not involve dust, but only very odd distributions of the dust and its source of heating can fit the observations. Must we fall back on that hand-waving argument that the centre of BL Lac contains a black hole, that ultimate condensed form of matter into which material is sucked at an alarming rate, radiating away its energy as it falls? Perhaps we must, but it is an unsatisfactory way out to pass the buck on to a phenomenon we do not understand – one that may not even exist.

### **BL Lac Objects as part of the Extragalactic Scene**

Whatever is going on in the centre of BL Lac objects is almost certainly related to what occurs in quasars and the nuclei of Seyfert galaxies, too. The difference is only one of degree. Quasars are more luminous, Seyfert galaxies less so. The BL Lac objects emit a greater proportion of their energy in the infra-red and are more violent and rapid variables. Even our own galaxy seems to have something of this, for the nucleus is a strong radio and infra-red source. In the visible, sadly, the nucleus of our galaxy is hidden by intervening dust, but there are some grounds for believing that could we see it we should describe it as having some of the milder properties of Seyfert nuclei.

## THE BL LACERTÆ OBJECTS

Just what it is that is occurring in all these objects we cannot say, and it will be some years before a picture emerges with any degree of coherence to it. But already we can see the similarities. There is some peculiar phenomenon of Nature which occurs in the nuclei of some galaxies. It is capable of creating energy at an incomprehensible rate. We can study it most readily in Seyfert galaxies, for some of them are relatively local objects, and this is probably the most important thing to do. Unfortunately, whatever it is the Seyferts have been invested with only a small share of it. Next after them the BL Lac objects are the nearest examples.

We may envisage some sort of sequence of objects according to the luminosity of their nuclei. Is this something that galaxies are born with? Is a Seyfert galaxy always a Seyfert, a quasar always a quasar? Or does some sort of evolution occur? If the latter, does it link the different types of objects, and in what sense? Does a Seyfert galaxy flare up to become a quasar or does a quasar run out of its great source of energy and settle down to become a Seyfert in its later years, and perhaps even a normal galaxy in its senility? These are the type of questions that are being asked as I write this late in 1974. They are questions that cannot yet be answered. But astronomers have fertile minds, and theories are continually being produced. How many of these will stand the test of time remains to be seen, and the best I can do to answer these problems is to state briefly what I consider to be a reasonably tenable theory at the moment. It goes thus:

A quasar is so violent an object that it seems unlikely that it could ever evolve into a Seyfert galaxy. The effects of having had so luminous a source at the centre would surely have disrupted any of the material that might later have formed the galaxy. Besides, Seyferts are too numerous: almost 100 are known and we have not yet sampled to the distance of the nearest quasar. No - Seyferts have never been as bright as quasars and probably never will be so; they were not intended to possess that degree of prominence. The BL Lac objects, though, are another story. We believe them to be nearly as luminous as quasars, and this suggests the two may be more closely related. It is then natural to

make BL Lac objects an early stage in the life cycle of quasars. Two arguments favour this arrangement. In the first place it is easier to postulate that spectral features of the form quasars exhibit develop from a bland BL Lac spectrum than to explain how a quasar's spectrum could disappear. Secondly, I noted above that we have difficulty accounting for the presence of dust. If the dust is being continuously destroyed, the great prominence of the infra-red emission should fall with time. Quasars do retain vestigial infra-red dust emission, but not of the amount that the BL Lac objects boast.

If, indeed, BL Lac objects are immature quasars, they deserve much more study. Especially they require extremely high spatial resolution observations. This is a job for a telescope above the Earth's atmosphere – the Large Space Telescope which is currently under consideration. With the sort of resolution the L.S.T. can offer we should be able to resolve the nucleus and study much better the associated galaxy. An accurate red shift would be possible, and confirmation that BL Lac really is an elliptical galaxy. Infra-red studies are needed at high spatial resolution too, to determine the distribution of the dust and hence infer something about the source or sources which heat it. An ultra-violet satellite such as I.U.E., the International Ultra-violet Explorer, could secure spectra to the blue of the visible region where stronger spectral lines occur which might feature in the spectrum of the nucleus. Even at optical wavelengths better spectra taken with the new digital devices (particularly that built by Alec Boksenberg of University College London) might show vestigial lines which would tell us much.

What this last paragraph was intended to show is that the BL Lac objects are a problem that classical astronomy cannot tackle. They are a problem of the 1970s, and one which can probably be solved only by the technology of the 1980s. This is the quintessence of a science like astronomy. As long as new techniques of observation are devised, new problems will arise demanding even more sophisticated techniques for their understanding. The BL Lac objects are one such problem.

# **Sense about Stellar Photography**

W. E. PENNELL

## **General**

I hope to be able to demonstrate that guided stellar photography of a quite adequate quality is within the amateur's grasp without great expense, but not without effort and enthusiasm – this is no attempt to say 'all made easy in six simple lessons' – and is not to be accomplished without some modest workshop provisions either. Again it is not appropriate to give specific instructions on 'how to do it', not least for the reason that telescopes and the essential complementary equatorial mounting come in all shapes and sizes, and I would hesitate to say that any are unsuitable. These notes are written pre-supposing some basic knowledge and experience, and in relation to modern 35 mm cameras and films in use with standard types of amateur equipment. While it is possible to achieve some results for the brighter stars and objects such as comets with short exposures (less than a minute) using fast wide-angle lenses and films, this will not be dealt with here – this article is concerned with the longer exposures needed to penetrate more deeply into the sky, and is in effect my own potted experience which I hope may be helpful in key areas.

## **Equipment**

The prime piece of equipment needed, and in all senses just as important as the telescope and camera is the equatorial, or more descriptively, the polar axis mounting – it is just this part of the equipment which enables either telescope or camera to follow the object being photographed for up to 30 minutes or so, compensating for the rotation of the earth which, astronomically

speaking, is a moving platform. Happily the Earth itself has 'good bearings' and for our purpose has an entirely stable and uniform motion, such that if the equatorial mounting has a similarly accurate but contra rotation, the star can be made to stand still while being photographed. Simple in principle and basically simple in practice; yet, despite the technical sophistication of our age, there is a surprising tendency to make heavy weather of its use whether for photography or for observing. Polar axis telescope mounts are capable of many variations in design – I shall, therefore, deal only with the common and essential details which are important photographically, and in relation to either the 'German' or the 'Fork' design, types most commonly in use (Figures 1–3).

There are three main areas for careful attention:

(A) *Provision for accurate and fine adjustments to the polar axis*

In amateur equipment, whether manufactured or home-made this most important need is usually ignored in the design until too late. Two separate adjustments are needed – altitude depending on latitude, and azimuth or direction – and provision for such movements should be thought of in terms of less than 1/1000 inch if the polar axis is to be set up within 1 minute of arc of the true pole, which must be the aim. 'Any old thing' just will not do. The equatorial mount shown in Figure 9 has a three-point base and anchorage which provides adjustments both in azimuth and altitude, but I prefer to use this provision for altitude only, and to provide a 'nudging plate' on either side for azimuth adjustment. When final adjustments are made, four small locking jacks are placed between the base plate and the underpart of the mount, two at each end to provide complete rigidity. Avoid 'delicate' mountings which are moved off line at the slightest knock. Robustness should be an aim all through. These remarks do not in any sense preclude the use of portable mounts which should be of the three-leg variety with adjusters on each leg.

(B) *Bearings*

Smooth free bearings *with no side play at all* are a must.

## SENSE ABOUT STELLAR PHOTOGRAPHY

Some amateurs successfully use the 'large wheel' or 'horse shoe' bearings for the polar axis, taking a tip from large professional instruments, but for the German type mount which I favour, my conclusion is that the old-fashioned split-bronze bush bearing is ideal, and that a fibre or nylon washer is all that is needed for the thrust bearing; and *please* avoid motor drives, setting circles, and any other sorts of impedimenta between the top polar axis bearing and the declination plate, and between the Telescope mounting plate and the adjacent declination bearing. These are always the weak places in any mount, and where flexing most easily occurs. The great advantage of the split-bronze bush is for the ease of hand fitting, as opposed to the 'all in one piece' nylon bearings illustrated in Figure 9 which are much more difficult to do, and if scraping is overdone there is no remedy. While the polar axis bearings are the vital heart, declination axis bearings need careful fitting, too. With an accurately set-up polar axis, adjustments in declination are just not needed for objects well up in the sky (say a minimum of  $30^\circ$  altitude) so this axis can be locked if necessary, but it is useful to have a fine adjustment free from all side play if photographing an object moving relative to the stars such as a comet. For the home doers, take as much care with the bearings as you do on the mirror.

### (C) *Drive and Control*

This is one of the all-important bits, and forgive me again for stating the obvious when I say that success depends on moving the telescope or camera on the polar axis at precisely the speed to match the contra rotation of the Earth. Since accuracy in even the best equipment is only relative, some means of regulating the drive speed is necessary, and it is usually required also to be able physically to follow a 'guide star' to provide an accurate and practical base for such regulations. Some amateur equipment on a permanent site, however, can be made sufficiently accurate in performance to take really good-class stellar photographs of fields of  $12^\circ$  and wider, without manual guidance, since the permissible margin of error is 20 seconds or so which is well within

the capability of amateur instruments if the operator wants to make it so. For prime focus photographs at the telescope, however, the need is for an accuracy  $<3$  seconds for good results, which is a very different matter – on this scale the minor mechanical errors of gear cutting, mounting errors in the worm drive, etc., make themselves very apparent, and rapid corrections have to be made.

All sorts of ingenious designs are seen on amateurs' equipment, and while clockwork drives once held full sway (and still die hard), my preference is the modern synchronous motor operating through a worm and drive wheel. The motors themselves which run off the ordinary 50-cycle mains have their own built-in reduction gears, and are not expensive, and are much better than secondhand gears bought for a bargain (sorry about this), or for that matter the gramophone type motor. Worm and drive wheel can be expensive, but as these are vital parts and beyond the manufacturing capability of most amateurs, I advise best quality and a little stretching of the purse strings. While 76 mm (3 in.) drive wheels can be adequate (Figure 12) if the teeth are fine enough, 178 mm (7 in.) drives seem the best compromise – such wheels require the worm to rotate 4 times per hour and are very easy to control. Larger drive wheels of the same pitch, while increasing accuracy in themselves, need higher worm speeds, say 15 revs per hour (Figure 9), which produces a certain 'busyness' in the guiding.

The big advantage of the synchronous motor for photographic use is that it is by nature inexorably locked on to the frequency of the power supply, and this is either precision controlled at the power stations (except in times of crisis) or is crystal controlled if a variable frequency oscillator unit is used and cannot vary except by a change in frequency.

Control is usually effected by varying the speed of the motor for guiding purposes, but I will outline first a simple mechanical control in which the motor runs at constant speed, Figures 12 and 13, which is most effective as applied to the type of portable mount illustrated (Figure 4), which is a popular design for 6-inch telescopes. For this, instead of mounting the motor on the boss at the lower end of the polar axis bearing, it is mounted on a  $\frac{5}{16}$  inch

## SENSE ABOUT STELLAR PHOTOGRAPHY

brass plate accurately fitting the shaft, and which has a lug extending upwards from the centre. The plate is oscillated by a simple screw and return spring device mounted on top of the boss. With a fine-threaded screw, say 40 to the inch, the desirable 3 seconds accuracy is possible. Direct control of motor speed naturally depends on the type of motor in use but for synchronous motors the very accurate control possible with modern variable frequency power units is certainly best, and settings once made are constant; this does permit the 'unguided' stellar photography mentioned earlier, which, of course, requires sidereal time as opposed to U.T. Both for safety and convenience I favour a 12v battery for a power source, and Figure 2 shows such a unit in use with a 12 a.h. motor cycle battery which is light and easily portable.

'Backlash' in the gear train has been made something of a bogey for amateurs, along with other things like reciprocity failure, and I think it should be clearly stated that unless you have a little play in the gears you will never have a smooth drive. Any good engineer will tell you that gears should never be set up tight (unless of the most expensive type), and I recommend an attitude of mind which accepts this and turns the necessity to good use instead of complaining. In a number of instances I have come across, the problem is not backlash at all but sloppy bearings allowing the shaft to move sideways. When all is well with the bearings the sort of movement permissible, as seen in the telescope, is 3 or 4 minutes of arc, which I find invaluable for orientation – whether for aligning the cross hairs in the guiding eyepiece or putting the picture frame of the camera E-W and N-S – how much better stellar photographs look when this is done, and a lot easier to use, too. To overcome the disadvantage of backlash, two things need to be done:

- (A) Balance the equipment in the RA plane slightly in favour of the East thus giving the motor a positive task. This is best gauged at the eyepiece by moving the telescope to the West and allowing it to drift back.
- (B) Have a means of applying a damper on the polar shaft (Figure

9), this is really only necessary when windy, and quite unnecessary when you have really good hand-fitted bearings of the split-bronze bush type – the lubricant in such cases is quite sufficient.

Synchronous motors with their own built-in gear train need virtually no attention but for the final drive – i.e. worm to drive wheel – I strongly recommend an oil bath where possible, the main function of which, apart from lubrication, is to wash and clean the gears. A particle of sand suddenly inserting itself between gear teeth can give a nasty kick when guiding (Figure 11).

### *Camera and Telescope*

The best starter for stellar photography is undoubtedly to go for wide-angle shots taken with a camera mounted on the telescope, using the latter for guidance. With the German type of equatorial telescope, the best place for the camera is the weight side of the declination shaft, on an easily constructed platform, the camera becoming part of the balance system (Figures 3 and 4). It is thus well removed from the telescope, which does not obstruct the field, but for fork-mounted telescopes the only place is on the tube or frame itself, and near the top to allow for a 40° field, and as some cameras are heavy this does create balancing problems which have to be overcome.

Guiding eyepieces have to be devised, and focal lengths of 18–25 mm are the easiest to modify. Those of the Kellner or Orthoscopic design have a positive focus a short distance in front of the object lens, and cross hairs have to be placed on the plane of this focus. This is easy to do by drilling 4 small holes in this plane 90° apart, and then threading through the filaments to be used, drawing them tight and securing them with tape on the outside. What I have used successfully is single-filament nylon, taken from an old wartime parachute which is very durable, although frustratingly fine to handle while fitting – once in place, however, it seems thick enough. On the same plane as the filaments a  $\frac{1}{8}$ -inch hole is drilled

any place in between the filament holes, so that a light source can be applied – for faint stars it is a great help to have the cross hairs illuminated. Illustrated in Figure 8 is a short length of alka-thene  $\frac{1}{2}$ -inch tubing cut to fit the eyepiece containing a 4.5v bulb running off a 1.5v battery held in place with a spring. Two or three thicknesses of white paper are still needed to reduce light level further. An alternative method recommended by H. E. Dall and others in the *B.A.A. Journal* is to mount a faint light pointing downwards in the guide telescope tube itself. I should explain here for those without previous experience that it is usual to put the guide star image out of focus, so that it forms a disk on which the cross hairs show up clearly.

A word here about the limiting magnitudes for guide stars in relation to apertures of guide telescopes may be appropriate, using the equivalent of a 9 mm guiding eyepiece – 60 mm refractor 3rd mag, 100 mm reflector 4.5 mag, 150 mm 6th mag, 300 mm 8.5 mag. For good guiding and avoiding excessive eye strain, the cross hairs need to be clearly visible against the out-of-focus star disk, and to secure adequate brightness on the fainter stars a small disk must be used. It is worth searching for the brightest star available since it is much easier on the eyes to have a large bright disk. For camera guiding, where the allowable margin of error can be 20 seconds or so, an 18–25 mm fl. eyepiece on its own is enough, but where higher accuracy for telescopic photography is needed, use with a  $\times 2$  barlow. There is some advantage in using a Newtonian reflector for guiding, since the flat creates a convenient black spot in the centre of the star disk, in the centre of which again is a very small white spot (why I don't know), but if you can keep this covered 80 per cent of the time by the cross hair you will have high accuracy. *One word of warning* here about the use of plastic tubes, either for guide telescopes or the main instrument – in operation over guiding periods of five minutes and over (i.e. the usual) they can and do sag causing errors up to 10 seconds or more, which is quite enough to spoil a telescopic photograph, however good the guiding may have been.

35 mm cameras are excellent instruments for stellar photo-

graphy, but they are not designed for such use, and worthwhile points arise from this:

- (A) There is a direct connection between width of field and fogging, i.e. the wider the field the bigger the problem, and special lens hoods are recommended, reducing say a 50 mm fl. lens to 40° from 45°, and in general better hoods are needed than those offered for ordinary use, which should aim just to cut the corners (see Figure 3).
- (B) Many wide aperture lenses are now available, but for quality images stop down to f4 at least on black and white – you will not lose as much speed as you think. For colour, however, wide apertures are not such a disadvantage, apparently due to the thicker emulsion, which is a help since such films are slower in speed.
- (C) Remember that filters placed in front of the object lens do not alter the focus, but if used in the converging light cone they do (say with a telephoto lens) and a new 'infinity' must be established.
- (D) *Films.* Everyone has their own favourite film and as long as results are satisfactory, no need to change. Stellar photography unlike planetary and lunar work does not as a rule involve high magnification of small objects, but on the other hand light from the stars, and especially nebulous objects is generally scarce, so what is needed is a fast film, preferably panchromatic, the latter if you wish to see the stars reproduced in the same form in which you see them visually. My own very definite preference is for TriX used with a  $\times 1\frac{1}{2}$  light yellow filter which gives a good visual sequence. For development I use D76 diluted 1+1 for about 30 minutes which up-rates the speed to 800 ASA or so, and gives the necessary high contrast. The only professional film designed specifically for astronomical use of which I have experience is 103 a-F and E. It is fast but rather grainy and somewhat better than TriX for galaxies and nebulous objects, and also for use with an objective prism, but for general work I would not rate it as good

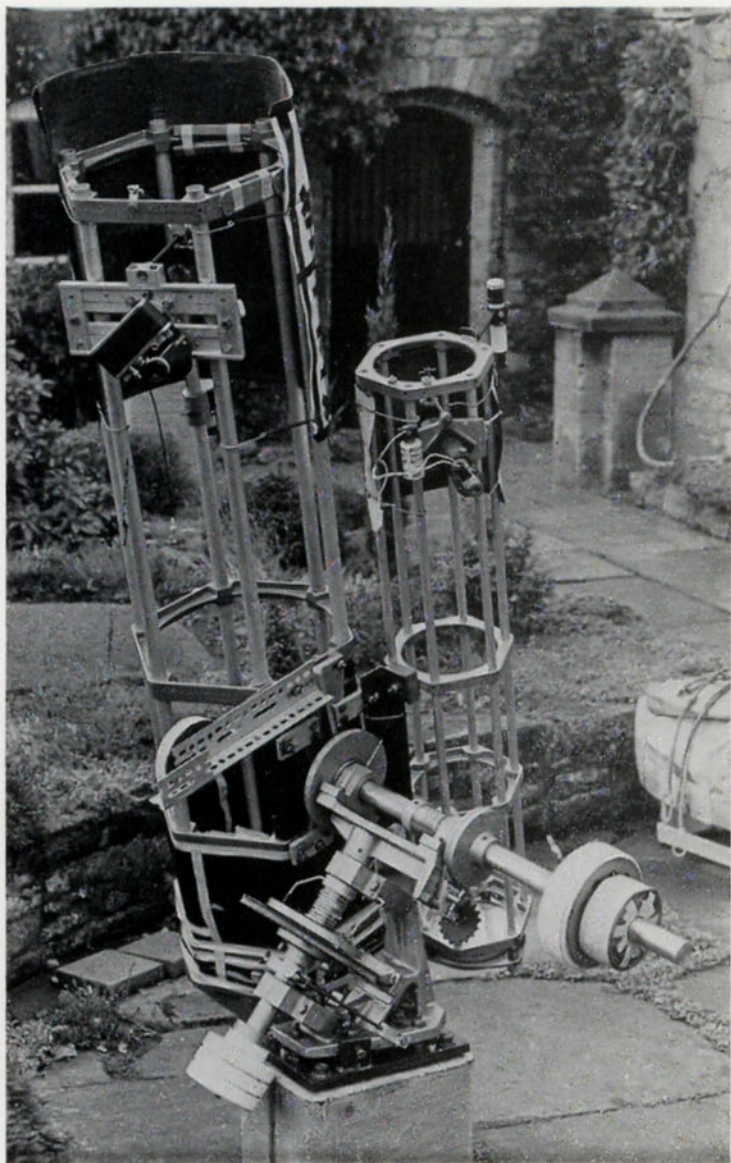


*Figure 1. 306 mm f5 reflector, set up for prime focus photography, using a 150 mm guide telescope. For good results, correct balance, both in R.A. and Declination, is most important – note use of counter weight for altitudes of more than 50°, and stabilizer on lower end of polar shaft. A sliding weight with quick locking is a time saver on the declination shaft. With open-tube telescopes, back screens are essential.*



*Figure 2.* The reflector, showing comfortable guiding position – the focusing mount and flat unit of guider can be moved around the tube giving choice of positions depending on location of object. See also variable frequency power unit operating from lightweight 12v battery.

*Figure 3.* Convenient camera platform and mounting for wide angle stellar photography. No manual guiding needed for 90 mm fl. lens here in use, taking  $21^{\circ} \times 14^{\circ}$  fields on this accurately mounted equatorial.

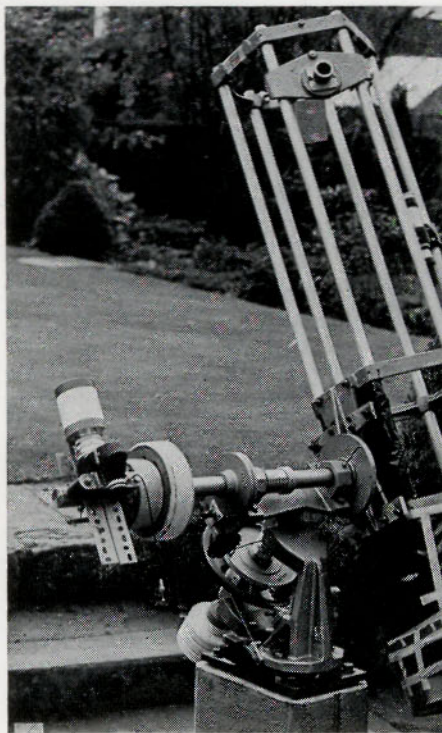


*Figure 4.* Popular type of portable 150 mm reflector, adapted for camera photography. Note guiding eyepiece with  $\times 2$  barlow in 150 mm, and flexible control for mechanical guiding system. See also text and Figures 12 and 13.

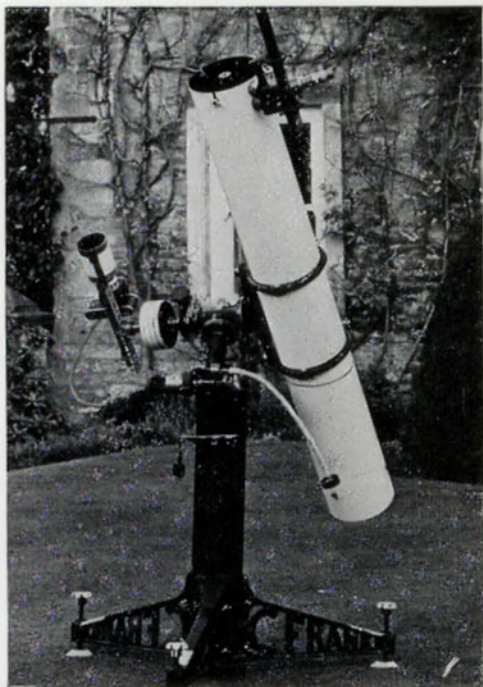


*Figure 5.* Lacking an observatory, telescopes keep very well under plastic covers in all weathers, if cotton wool pads are kept in firm contact with mirrors.

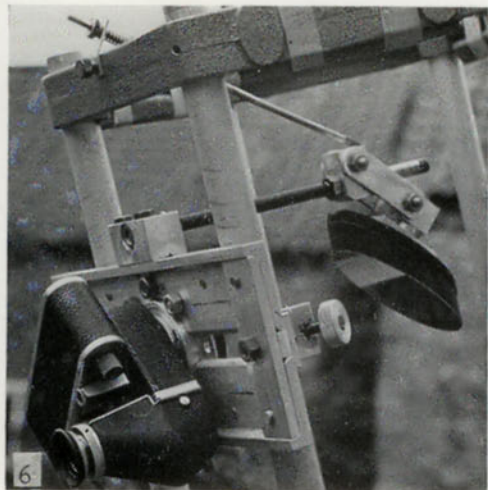


*Figure 6 (left) and Figure 7 (below).* Special photographic flat unit, bringing camera body as close to telescope tube as possible, avoiding focusing tubes. This makes full field photography possible at prime focus – here the field is  $90' \times 60'$ , and what you need for the Orion Nebula, for instance. Focusing is by sliding the plate on frame, with a micro-focus device operated, by applying tension to flat with a screw and return spring.

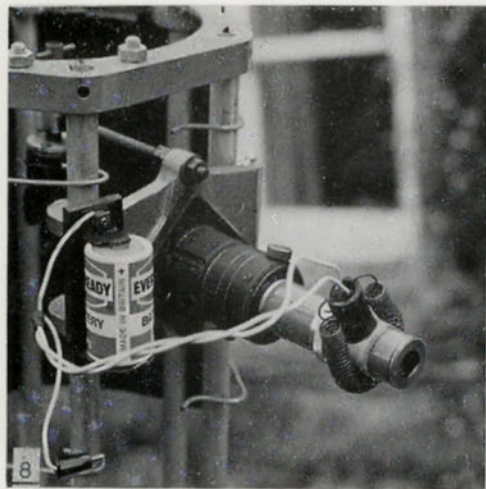
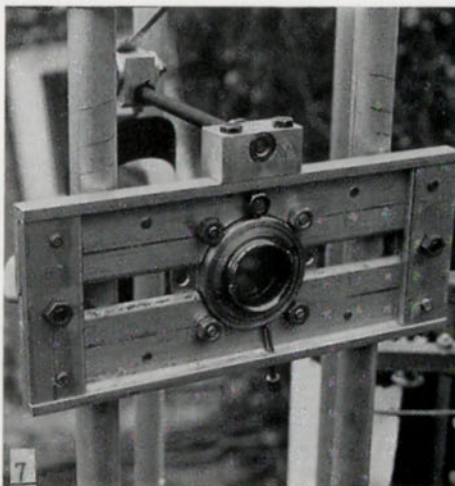


*Figure 8.* Guiding eyepiece in position with  $\times 2$  barlow, nett fl 9 mm. Note easily detachable illuminator for cross hairs.

*Figure 9.* Note base plate for polar axis mount, showing adjustments in azimuth and altitude, also locking jacks in position. Here is a 250 mm drive gear with worm rotating at 15 revs per hour. Also shown is shaft damper for steadying drive under windy conditions, the shaft is 38 mm diameter and runs in one-piece nylon bearings.

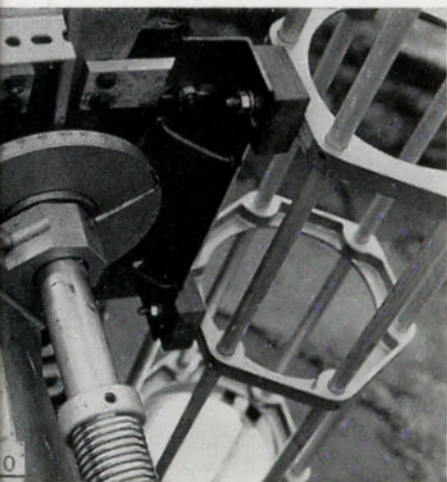
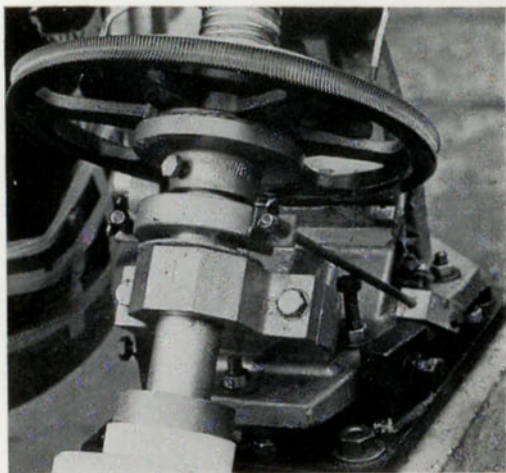
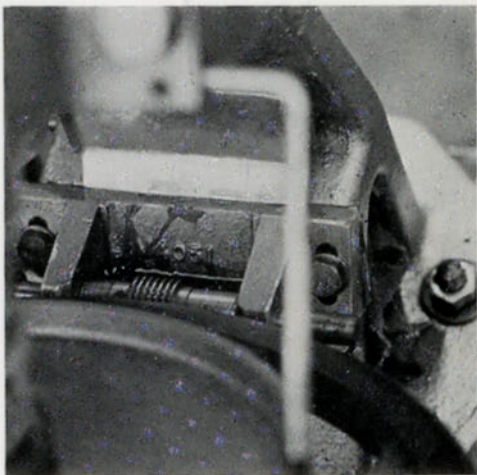


*Figure 10.* Slotted angle-iron mounting for guide telescope, permitting  $\pm 5^\circ$  movement on both axes.

*Figure 11.* Oil bath for worm drive. Worm gear has 6-point locking on drive shaft to avoid eccentricity and consequent periodicity.



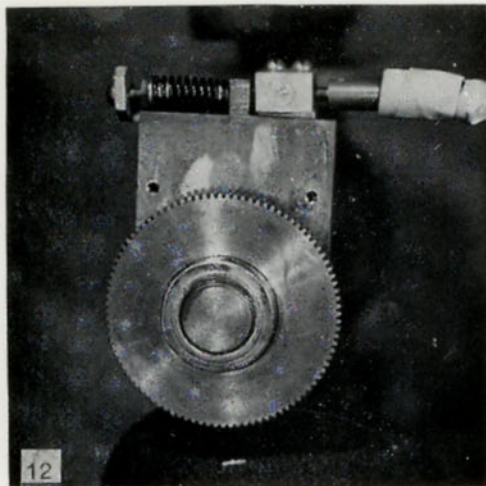


Figure 12 (left) and Figure 13 (below). Details of 'rocking plate' system of mechanical guiding. Figure 12 shows motor removed with screw and return spring mechanism operating on lug at top of plate. Constant speed synchronous motor runs at U.T.

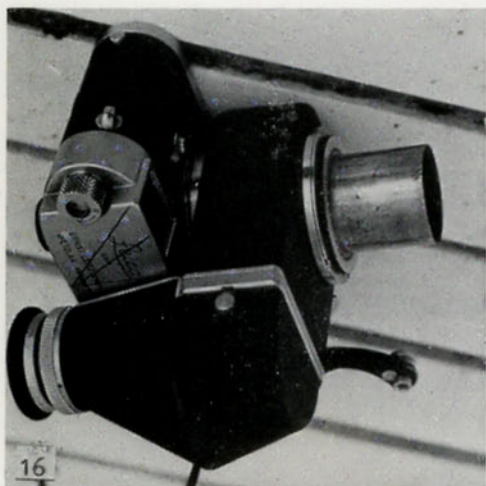
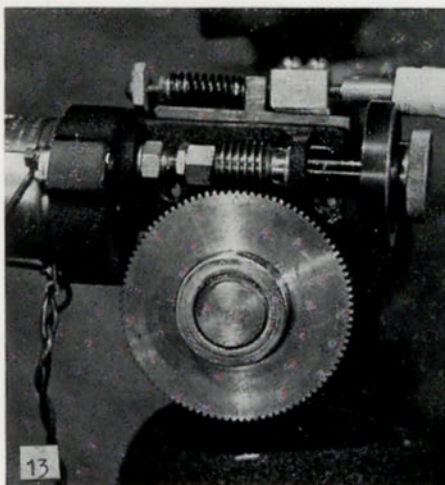
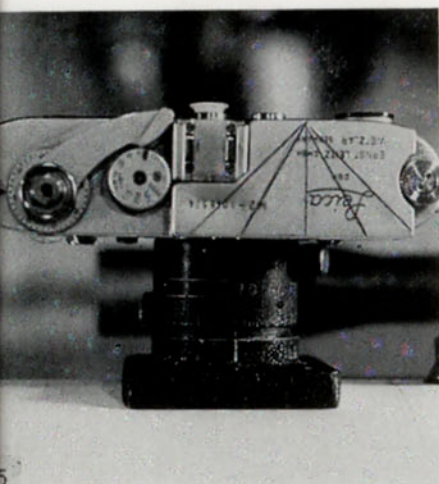
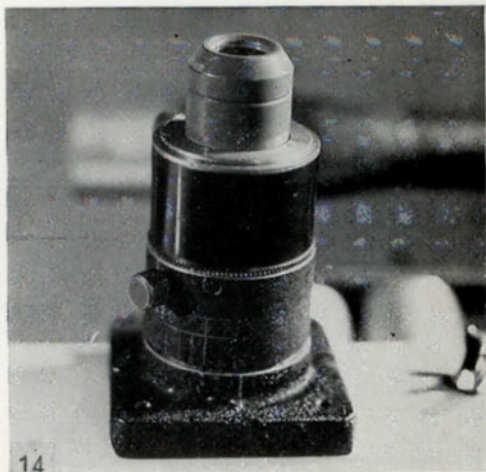


Figure 16 (left) and Figure 17 (right). Standard 1 1/4 in. push-fit eyepiece attachment for camera. Note locking screws to secure

Figure 14 (right) and Figure 15 (below). Two-tier eyepiece and camera mount for prime focus photography with a 150 mm tube type reflector with fixed flat.



both camera and focus. This adaptor can house a barlow lens of not more than 75 mm — fl.

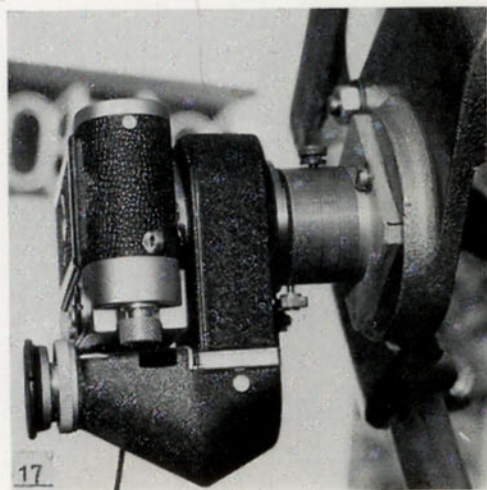




*Figure 18.* Orion Nebula M42, S, taken 7 December 1970  
(26 cm 30 m TriX 10' = 24.7 min).

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as the latter. For colour work I have not found anything better than High Speed Ektochrome or Ansachrome, 300 or 500.

### *Prime Focus Photography*

It is time now to consider photography with the telescope itself, which does require special adaptations – and where you either need a small workshop, or a friend nearby who has one. Basically there is no difference whatever between this and an ordinary camera, despite the title, but in this situation, the camera lens is removed (yes, I am afraid you need a camera where this can happen) and the camera body must be so attached that the object lens or mirror of the telescope focuses on the film at the back of the camera – this is known as the prime or first focus. This is where a problem arises in some telescopes, ‘getting the prime focus where you need it’, since if you fit the equivalent eyepiece adaptor to the camera body (Figure 16) the normal focus position will be anything up to 50 mm short of the film, and there is no simple adjustment as a rule that can be made to fixed-focus tube-type telescopes. Two suggested modifications to overcome this are as follows:

- (A) To move the mirror an equivalent distance up the tube, in which case it needs to be moved back again for observing.  
or
- (B) To modify the focusing mount – probably the best compromise will be a bit of both; a two-tier focusing mount which can easily be converted back for observing, and the mirror moved up permanently, say half the distance otherwise needed (Figures 14 and 15).

I think it will be appreciated looking at Figure 1 that by far the most adaptable telescope for stellar photography is the open-frame tube, where flat and focusing mount are one unit and can be moved up or down to bring the focus just where it is needed. Figures 6 and 7 show a special photographic flat unit eliminating focusing and draw tubes, and bringing the camera body right up to the side of the tube – this is essential for a full field, note large aperture of

filter (Figure 7). It is advisable to check that the flat is of a sufficient size to bring full mirror power to all parts of the field required – as illustrated a 90-minute field is needed requiring a 76 mm flat, but a 64 mm flat is enough for observing (for a 306 mm f5 mirror). Basic focusing is by sliding the unit up or down, reasonable accuracy is possible, and fine final focus is applied through tension to the flat with spring-loaded screw on top ring (Figure 6). However, this special flat unit is only a refinement and by fitting an eyepiece adaptor to the camera, the ordinary flat and focusing mount serve quite well, except that the field will be limited with only the central area of the film fully exposed. The eyepiece adaptor may also be used to house a barlow lens of  $-75$  mm fl. or less to give a  $\times 2$  prime focus image (Figures 16 and 17).

Finally, the choice of a camera – there is little doubt that the SLR 35 mm type with a removable lens is the one best suited to amateur stellar photography, on grounds of general adaptability, low film costs, and simplicity of operation. Whatever camera is used, the lens must be removable, and an accurate focusing system devised. The Leica body used with the 15 cm telescope (Figure 15) is pre-focused with the aid of a screen fitted to the back, and a calibrated focusing mount.

### **In Practice**

#### **(1) *Setting up the Polar Axis***

As previously outlined, it is well within the capabilities of amateur equipment, if permanently mounted, and with a sensible design, to be made to steer itself with sufficient precision to take good quality wide-angle stellar fields of say  $12^\circ$  and over, using a synchronous motor operated through a variable power unit of stable design. To do this takes time and patience, but is nevertheless a most interesting exercise which I recommend. Most of the fine adjustments can be made in daylight, which is a great saver of observing time, but setting circles are a must for this; I do not think it is generally realized how easy it is to pick out 1st mag stars any time in the day, provided they are not too near the Sun – nothing more pretentious than a 60 mm refractor is needed for this

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exercise, and there are only two other provisos – the focus must be pre-set or marked, and it must be pointed within say 30 minutes of the star's position, to pick it up in a low-power eyepiece.

Assuming that the polar axis has been set as accurately as possible with the aid of the Pole Star, remembering that for azimuth corrections it must be in a N or S position relative to the true pole, and E or W for altitude, the setting circles can then be set and will be accurate enough to pick out a first magnitude star – once found, accuracy of the circles can be progressively improved from the known co-ordinates of the stars found or, of course, this can easily be done at night. One keen amateur I know has a long list of 40 or 50 daylight stars he has found down to 4th mag with a 4-inch refractor. Once found and centred, fit the guiding eyepiece, and make use of the backlash in RA to orientate the cross hairs N-S and E-W. Having done this you can start to kill two birds with one stone; one to regulate the drive speed in RA, and then to note whether the star drifts up or down in declination. Firstly, make a start with azimuth corrections, and for this choose your time and a star within two hours of the meridian, preferably rising, and not too far from the equator – my choice of suitable stars according to time of year would be Aldebaran, Betelgeuse, Procyon, Regulus, Arcturus, Altair. In reading correctly the drift you will almost certainly see, and assuming that you are looking at an inverted image – if it goes up, rotate instrument clockwise, and vice versa; be bold for a start, say 30 minutes or so to be sure to 'bracket' the true direction, so having a firm + or – situation to work on, and continue to correct until the star remains steady on the cross hair for 20 to 30 mins. Then switch to a star reasonably well up in the sky + or – one hour of due E or W, and for this Vega and Capella are ideal, and repeat the exercise to correct for altitude – increase altitude if star falls and vice versa – taking care not to move the mount in azimuth. Of course, there is a small factor of atmospheric refraction I must mention for the theorists, but ignore this in your adjustments, and you will finish up with a built-in correction for most declinations, which in fact will be a few seconds above the true pole in altitude.

*(2) Star Fields and Exposures*

For camera shots as illustrated in Figures 3 and 4 it is not difficult to select an intended field – first find a suitable guide star as near to the field centre as you can, and then align the camera through the reflex screen or viewer, having previously pin-pointed the centre of the field in the sky, say with the aid of a sky map. With the wide field of a camera lens there is always a generous error margin.

If, by now, you are satisfied that the equatorial mount and drive are accurate enough without manual guidance, all you need do is to align the centre of the camera field with the telescope, using a bright star, and then select the field centre with the aid of the setting circles.

For telescopic fields of the order of  $1^\circ$  or so (Figure 1), where pin-point accuracy is needed, care is required even with accurate setting circles and the only successful way is to identify the pattern of stars in the field either through an eyepiece before fitting the camera or on the reflex screen (reflex screens reduce seeing by about 2 mags). Smithsonian Astrophysical Observatory Star Charts which go to 9th mag are perhaps the most useful for this purpose, and an additional help is a photographic atlas. A suitable drill, having centred the field is then to line up the guide telescope with the best guide star available, and it saves time if a check is made in advance from the star chart where this star is likely to be in relation to the field. Guide telescopes need to have an off-setting capability of 4 or 5 degrees in both co-ordinates, and a convenient mounting with the aid of a slotted angle-iron is shown in Figure 10. First place the guider in approximately the right line so the star can be picked up in the finder, making final adjustments to bring the star into the telescopic field with low power, checking that the object to be photographed is still centred in the main telescope – most important! For manoeuvring the guide star on to the cross hairs I use the mirror collimation screws of the guider. When all is tightened up, balancing and focusing carefully completed, a start can be made. My method is to focus visually on a 2nd mag star, usually after setting the guide scope, returning to

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the correct field with aid of the setting circles and finally picking up the guide star again. All this sounds pretty tedious, but once a drill is established it is easier than the words indicate, so please don't be put off! the results will be well worth it.

*Exposure Times.* Old ideas die hard in astronomy as elsewhere, and the memory lingers on of the mammoth exposure times of the pioneer stellar photographers such as Ritchey and Hubble, which were sometimes spread over two or three nights, totalling eight hours or more. Such exposures may have been necessary then owing in part to the slow emulsions available, and in part to the long focus (and consequently slow) telescopes in use. This situation has now entirely changed, and yet modern writers on astro-photography still tend to talk in terms of  $1\frac{1}{2}$  to 2 hours exposure times, which is very misleading. Good guiding with amateur equipment requires concentration and 40 minutes is the longest exposure that can gainfully be used on TriX and personally I would avoid such a penance unless I had a willing assistant; 30 minutes is usually my limit. The best advice I can give is to limit the exposure time to the minimum needed for any particular object, since the longer the exposure the greater the possible errors, whether mechanical or personal, to say nothing of fogging. Mention of 'reciprocity failure' tends to raise my blood pressure, since there is no doubt it has been made a bogey for many aspirants and is used by some as a convenient whipping boy for their failures. Really RPF is a very minor problem if exposures are limited to a maximum of 30 minutes and good results came to me before I ever heard of it – it means, in effect, that a film gets tired with prolonged exposure, and over a period gradually loses its sensitivity to the light it is receiving. As previously indicated, the useful time limit for TriX is about 40 minutes – well beyond normal exposure times. All that is wanted is a sense of proportion – do not worry about the fine points, which I know make good armchair talk, before you have mastered the basics, such as the bearings and alignment of the polar axis, drive, etc.

## 1976 YEARBOOK OF ASTRONOMY

As a philistine may I advise having a go first, and reading the books afterwards (in part at least).

The following Exposure Guide is from personal experience and relates to TriX used with a  $1\frac{1}{2} \times$  light yellow filter, and developed for 30 minutes in D76 1 + 1:

|                  |      |         |               |
|------------------|------|---------|---------------|
| 50 mm fl camera  | f4   | 10 mins | 10th mag      |
| 90 mm       ,,   | f4   | 10 mins | 11th mag      |
| 280 mm       ,,  | f5.6 | 10 mins | 12th mag      |
| 260 mm reflector | f5.5 | 20 mins | 15.5/16.0 mag |
| 306 mm       ,,  | f5   | 15 mins | 15.5/16.0 mag |
| ,,       ,,      | f5   | 10 mins | 15.0/15.5 mag |
| ,,       ,,      | f5   | 5 mins  | 14.5/15.0 mag |

The above table relates also to good average conditions – on rare occasions performance may improve by nearly 1 mag, and very frequently on class 2 nights the reverse – I do not enter into any competitions over this!

In general terms 10 minutes with fast black and white film and an f5 or f6 telescope covers most amateur needs, and it is only faint nebulous objects which require 30 minutes or so, such as the Veil nebula in Cygnus, the Horse Head in Orion, and the disk of M31 to give just three examples. M42 and M51 do very well on 20 minutes; M57 and M27 on 10 minutes, even with an f8 150 mm reflector. Spectroscopic film 103 a-F is rather speedier for such pictures, particularly where there is a large component of H-alpha light, but it does not seem to record fainter stars than TriX.

Colour is, unfortunately, a different matter for the amateur, unless he is prepared to process his own films and uprate them in so doing, lack of speed is a serious drawback, nor, astronomically speaking, are they of much use except as pretty pictures.

# Black Holes

DAVID L. BLOCK

The turn of the twentieth century marked the commencement of a new era in physics: in 1900, the groundwork for modern atomic physics was laid with the introduction by Planck (1858–1947) of the idea of the quantum. Some five years later, until which time the Newtonian theory of gravitation was never seriously challenged, Einstein formulated his Special and later General Theories of Relativity. The latter pointed to three observational phenomena (now known as the three classical tests) which would occur if the axioms of his basic theory were well founded. These are the gravitational redshift of spectral lines, the deflection of light by a gravitational field, and the advance of the perihelion of a planetary orbit. These events are governed and predicted by Einstein's 'field equations', which are non-linear and usually exceedingly complex to solve unless certain simplifying assumptions are made.

In 1916, the German astronomer Schwarzschild obtained the first exact solution to the field equations. This solution describes how space-time (in which, to define an event, three spatial and one time coordinates are required, since we are dealing in four dimensions – this concept of an event only holds at a classical and not quantum level, as shall be discussed at a later stage) is curved by the gravitational field of a star which is perfectly spherical and which is not rotating.

By a well-known theorem in General Relativity formulated by Birkhoff, it is possible to prove mathematically that the external geometry of a star which is not at rest but is collapsing without rotation or deviation from spherical symmetry is still part of the Schwarzschild geometry: in other words, such a star has the

same external field as a star, of the same mass, at rest. This applies equally well to a star pulsating radially, so that spherical symmetry is constantly maintained. Once the gravitational field of a spherically symmetric body at rest has been determined, so has the field of any collapsing or pulsating star under the above conditions. Formulated more precisely, a spherically symmetric solution of the vacuum field equations (for example, no charge) is necessarily static (field is time independent and spatially isotropic).

Examining the Schwarzschild solution, it is found that time and space become interchanged in an unusual manner if a collapsing star reaches a certain critical radius, termed the Schwarzschild radius. It is determined by the formula  $2GM/c^2$ , where  $G$  denotes the Newtonian constant of gravitation,  $M$  is the mass of the star, and  $c$  is the velocity of light *in vacuo*. Once the radius of a star collapsing without rotation or deviation from spherical symmetry has reached  $2GM/c^2$ , a black hole results, where gravity overwhelms all other forces, and collapse continues unabated. This is because space and time then become interchanged: the direction of increasing proper time (time as measured by a fictitious co-moving observer who stands on the surface of the freely falling star as it collapses) is the direction of *decreasing* values of the radial coordinate,  $r$ . In other words, an exploring astronaut, once inside the Schwarzschild radius, has no power, no matter how he may boost his rocket engines, to return to a larger radial value than he has power to turn back the hands on the clock of life itself! Neither can he remain at any particular radial position, for the simple reason that no one has the power to stop the advance of time. He is causally cut off from the rest of the Universe, and collapse to the centre of the hole where matter becomes squeezed to infinite density and zero volume – the singularity – is unavoidable.

The surface determined by the Schwarzschild radius is termed the event horizon, and is the limit from within which no light, matter or signal of any kind can escape. At the event horizon, the curvature of space-time is not infinite, as might originally be supposed. It increases without limit, however, as the singularity

is approached. (For those interested, the scalar  $R^{abcd}R_{abcd}$  diverges to infinity as  $r = 0$  is approached;  $R$  is the Riemann curvature tensor.)

Let us now examine under what conditions a star can collapse to the Schwarzschild radius to form a black hole.

The proton to proton reaction is believed to be the principal source of stellar energy at temperatures of below about 15 million degrees Kelvin. In the Sun, for example, four hydrogen atoms combine to form an atom of helium, with a consequent release of energy: at the solar centre; 600 million tons of hydrogen are converted into helium every second, corresponding to a mass 'loss' of 4 million tons per second. This 'missing' mass has, of course, been converted into energy via Einstein's famous special relativistic formula  $E = mc^2$ . The hydrogen nucleus contains one proton and the helium nucleus four; the hydrogen atom has an atomic weight of 1.008, and thus four would have a combined weight of 4.032, but a helium atom has an atomic weight of, not 4.032, but 4.004. How can this be? The difference of 0.028 is due to the loss of mass in the form of energy released by the transformation process.

In General Relativity, one speaks of a 'mass-energy', since mass has an effective energy associated with it, related by  $E = mc^2$ .

Numerical computations of the fate of a star reaching the end of its thermonuclear life have primarily been based on the star's mass. This does not imply that effects such as rotation do not play significant roles, but these are often neglected in order to simplify the computations. (Those readers interested in studying the effects of pressure, rotation, and magnetic fields on the collapse may refer to a paper by the author in volume 15 of the *Quarterly Journal of the Royal Astronomical Society*, and references cited therein.)

If the mass is below the Chandrasekhar limit of 1.2 solar masses, the star can attain equilibrium as a white dwarf. White dwarfs, with radii of about 5,000 kilometres and densities of about 1 ton/cm<sup>3</sup>, support themselves against gravity by the pressure of degenerate electrons. Stars reaching the endpoint of their evolution whose mass exceeds this limit cannot become white dwarfs; the star's

internal pressure fails to support it, and one of two possibilities ensues, depending on whether the core mass and its kinetic energy of collapse does or does not suffice to drive the system on beyond nuclear densities to the point of complete gravitational collapse to a black hole. If the mass is too small (this will be clarified presently) or the velocity of collapse is too low, computations reveal that collapse is halted at nuclear or near-nuclear density. This stopping results in the sudden conversion of an enormous amount of kinetic energy, forming a supernova with a super-dense neutron star. Neutron stars have radii of some 10 kilometres and densities of about  $10^{14}$ g per cubic centimetre. They are supported against gravity by the pressure of degenerate neutrons and by nucleon-strong interaction forces.

The limit above which a star cannot reach equilibrium as a neutron star is known as the Oppenheimer-Volkoff limit: the value given by Oppenheimer and Volkoff was about 0.7 solar masses. Ruffini and Rhoades have established, on the sole basis of the General Theory, the principle of causality and Le Chatelier's Principle, that the maximum mass of the equilibrium configuration of a neutron star cannot be larger than 3.2 solar masses (the principle of causality demands an equation of state with a speed of sound always smaller or equal to that of the speed of light, while Le Chatelier's Principle states that the rate of change of pressure with the change of density is always positive).

If the core of the collapsing star is too massive (exceeds the Chandrasekhar and Oppenheimer-Volkoff limits), or if it collapses with too much kinetic energy, the collapse may still slow down as nuclear densities are encountered, but at this stage gravity, the weakest of the four known forces at the atomic and nuclear levels, becomes the overwhelming force, and complete gravitational collapse to a black hole follows.

Summed up in the words of Thorne and Novikov:

'Modern computations (let us keep in mind the very primitive state of the modern computations – for example, their typical neglect of the effects of rotation) conclude that stars whose

masses exceed the Chandrasekhar limit of 1.2 solar masses, at the endpoint of their evolution, should explode as supernovæ. A supernova explosion can leave behind two remnants: an expanding gas cloud (the outer part of the original star), and a remnant "star". The remnant "star" will be a neutron star if its mass,  $M_{\text{remnant}}$ , is less than approximately two solar masses (here one should not ignore the large mass defect for massive neutron stars), but will be a black hole if its mass is greater than about two solar masses.'

In the Schwarzschild solution, a black hole resulting from the spherically symmetric collapse of a star to within the Schwarzschild radius, is characterized by a spherical surface whose radius is as we have seen proportional to its mass, determined by  $r = 2GM/c^2$ . Only from points exterior to the horizon can signals be emitted which do escape – at any interior point, the decrease of the radial coordinate denotes the progress of time, and the signal can never escape.

At this point, it is interesting to note that Newtonian theory does not predict black holes, even though it should be mentioned that in 1798 Laplace wrote:

'A luminous star, of the same density as the Earth, and whose diameter should be two hundred and fifty times larger than that of the Sun, would not, in consequence of its attraction, allow any of its rays to arrive at us; it is therefore possible that the largest luminous bodies in the universe may, through this cause, be invisible.'

In Newton's theory, light remains unaffected by gravitational fields, and velocities greater than that of light are allowed. Papapetrou has recently pointed out that gravitational collapse might in principle also occur in the Newtonian theory of gravitation. He notes:

'If the equation of state predicts an increase of the pressure

which is slower than needed to halt the contraction, we shall finally get a point singularity at the centre. This singularity is of a much less drastic character than the one in the Schwarzschild solution. Indeed, in the Newtonian case we only have the gravitational acceleration tending to an infinite value when  $r$  approaches zero: *the space is still Euclidean (flat)* and it is always possible to continue a straight line beyond the point  $r = 0$ . On the contrary, in the Schwarzschild case the geometry degenerates at the point  $r$  equal to zero in such a way that it is impossible to continue a geodesic (path of a particle or light in space-time) beyond this point.'

The description of black holes requires Relativity from beginning to end. A noteworthy fact is that the Brans-Dicke-Jordan scalar-tensor theory, which can be regarded as the most serious rival to Einstein's theory, leads, in the words of Penrose, to 'a black hole picture identical with the one arising from Einstein's theory'.

Let us now consider the spherically symmetric collapse of a star to the Schwarzschild or gravitational radius as seen by an external observer. The total time for an observer co-moving with the stellar matter is finite, and for the idealized 'zero pressure' model (in which pressure within the star is neglected) and typical stellar masses, is of the order of one day; an external observer, however, sees the star asymptotically shrinking to its gravitational radius. As the star collapses toward the critical radius, the red shift of light progressively increases, becoming infinite at the radius  $2 GM/c^2$ , and the star fades out of sight. Hence the name 'frozen star' used in pre-1970 black hole physics. To an external observer, the time scale of catastrophic gravitational collapse is exceedingly short. The time in which the red shift grows exponentially to infinity is of the order of  $10^{-5} M$  seconds, where  $M$  denotes the mass of the collapsing sphere in units of solar mass. Consider a sphere of  $10^8$  solar masses and radius 100 light-years in the process of collapse toward the Schwarzschild radius. It can be shown that the red shift for the first  $10^5$  years of collapse is of the order of  $10^{-3}$ ,

and it then grows exponentially to infinity in a time of the order of one minute!

The careful reader may now enquire: 'Since the time as measured by a distant observer for the star to collapse to the gravitational radius is infinite, how can an astrophysicist on Earth ("distant" observer) speak of a black hole in a binary system, if relative to him the collapsing star which would constitute the hole never in fact reaches the black hole stage?'

The answer to this question is two-fold. We shall firstly have to consider what is meant by the external gravitational field of a black hole (since no matter within the horizon can manifest its influence on events outside the event horizon). The second point to note is that the exact two-body problem in General Relativity has not been solved. In other words, one cannot show by the use of General Relativity that a black hole can be a member of a close binary system. Regarding the fact that black holes appear as solutions of Einstein's field equations, McVittie comments:

'These solutions presuppose that the body whose collapse forms the hole is entirely isolated, and that the only gravitational field present is its own. These presuppositions are far from being realized (when it is written that) a black hole could be a component of a close binary system.'

The absence of evidence of a solution to the two-body problem does not imply the evidence of absence of such a solution: it does not imply that a black hole can not be a member of a close binary system, but it nevertheless cannot be proved using General Relativity that it is.

Returning to the first point raised concerning the external field of a black hole, it must be remembered that *before* the star collapses to the gravitational radius, the external geometry is described in the case of a spherically symmetric collapse by the Schwarzschild solution. As the star collapses through the radius, no signal, light, or radiation of any kind can escape. Thus, when speaking about a

black hole's external gravitational field, one is in fact referring to its external geometry as it was when the star collapsed through the horizon to form the hole.

With this at hand, we may now answer the question. Consider a star in orbit about a black hole. Any infalling matter does reach the event horizon in finite proper time (recall that to a co-moving observer the collapse to the Schwarzschild radius takes a finite amount of time), and during the process may emit X- or even gamma-rays. When this radiation is detected on Earth, the hole has, of course, manifested its influence on the radiation, since it initially originated in and subsequently propagated through the external field of the hole before reaching the observer.

We have so far only considered a non-rotating spherically symmetric star collapsing to form a black hole. Using Birkhoff's theorem discussed above, provided spatial isotropy is maintained, the external gravitational field remains that of the Schwarzschild solution whether or not the star is collapsing or pulsating. More realistically, if the star is rotating or has an associated electromagnetic field, the appropriate solution to the field equations for the resulting black hole is that discovered by Kerr and Newman, together with their co-workers. The Kerr-Newman geometry describes possibly charged and rotating black holes, and reduces to the Schwarzschild geometry when the charge and angular momentum are both zero. In the case of zero angular momentum but charge, the solution assumes the Reissner-Nordstrom form.

One might expect that each black hole is characterized by many parameters, which vary from hole to hole, depending on the initial configurations of the star.

Carter, Hawking, and Israel have, however, shown that a black hole is characterized *uniquely* by its mass  $M$ , charge  $Q$ , and angular momentum  $S$ . Initially, other constraints are produced by the distributions of mass, momentum, stress, charge, and current inside the star. But as the star collapses through the event horizon, cutting itself off causally from the rest of the Universe, the only subsequent parameters characterizing the external gravitational

field are  $M$ ,  $Q$ , and  $S$ . The settling down involves dynamic changes of the fields and an associated outflow of gravitational and electromagnetic waves, but the process will converge rather quickly. It should therefore be emphasized that only well after the collapse occurs (asymptotic future) and in the region at and outside the event horizon, is the Kerr-Newman geometry a faithful descriptor of a black hole.

It is, in principle, possible to extract energy from a rotating or charged black hole via the Penrose process, which makes use of the ergosphere. The ergosphere is that region of space-time between the event horizon (surface of black hole; boundary of the region from which no particle can escape to a distant observer at infinity) and the surface of infinite red shift, known as the static limit. The static limit coincides with the horizon only in the case of the angular momentum and charge-free Schwarzschild black hole; for a rotating hole, the red shift of light becomes infinite as the static limit is approached.

In the Penrose process, a particle is sent by a distant observer to within the ergosphere, and decays there into two particles. One emerges with a greater energy than the energy of the original incoming particle, while the second is captured by the black hole! The outgoing particle can escape from the hole, since the process takes place in the ergosphere, which is exterior to the event horizon. Actually, in the Kerr solution there are two horizons, so in the above discussion reference has only been made to the outer horizon. Energy extraction does therefore change the external field of the hole; characterized by the three parameters  $M$ ,  $Q$ , and  $S$ . Such extraction would be possible until the time by which all charge and angular momentum had been removed, and the mass had dropped to a final 'irreducible' mass. Once this stage has been reached, it would be an impossible task to extract any further mass-energy, since we would be left with a 'dead' non-rotating Schwarzschild black hole. It has, however, been shown that this process cannot be efficiently employed in realistic break-ups of astronomical bodies.

**The singularities encountered in rotating and non-rotating black**

holes reflect a fundamental change in the character of this region of space-time. In the non-rotating case, collapse to the singularity is unavoidable, but in a Kerr-Newman black hole the singularity need not be unavoidable. This is formulated by asserting that in the Schwarzschild solution a space-like singularity exists, while in the Kerr-Newman solution one is confronted with a time-like singularity. What are the possible implications of this? It may be shown mathematically, using a so-called Kruskal diagram of the Kerr solution, that a rotating black hole may be thought of as forming a bridge which connects an infinite number of otherwise separate universes.

Consider an astronaut passing through the event horizons of a rotating black hole. Since the singularity is time-like, he may leave the inner and outer horizons behind (provided he is not foolish enough to head straight for the singularity) and emerge into another universe! Although this is not possible in the Schwarzschild solution, there is an interesting surprise in store. If one follows the continued spherically symmetric collapse of a star one also finds that space-time eventually opens up into another universe. The bridge linking the two universes is known as the Einstein-Rosen bridge or wormhole. However, in this case where the black hole is not rotating, a space-flight to communicate with the second universe is impossible, for it would involve a velocity of travel greater than the velocity of light.

In summary, then, the geometry of space-time of a black hole is rather surprising. The Schwarzschild solution actually consists of two solutions, one connecting our universe to the event horizon, and the other continuing into another universe with which no contact could be made. The Einstein-Rosen bridge connects these two asymptotically flat universes. These universes need not be distinct: the wormhole could be connecting two very distant parts of our own universe. In the Kerr solution, however, space-flight trips between universes are possible, since the singularity is time-like and avoidable.

This has led to the speculation of white holes, the time reversals of black holes. Basically a white hole is an object exploding from

a highly dense or singular state. It has been suggested that perhaps at the centres of exploding and peculiar galaxies, we have the 'other end' of a rotating black hole, where matter and energy is gushing up out of the throats of rotating wormholes which connect our universe to a variety of other universes.

On the existence of wormholes in nature, Misner, Thorne, and Wheeler note:

'As a solution to Einstein's field equations, this expanding and recontracting wormhole (in the Schwarzschild geometry) must be taken seriously. It is an exact solution; and it is one of the simplest of all exact solutions. But there is no reason whatsoever to believe that such wormholes exist in the real universe. They can exist only if the expanding universe, approximately  $10 \times 10^9$  years ago, was 'born' with the necessary initial conditions - with ' $r = 0$ ' Schwarzschild singularities ready and waiting to blossom forth into wormholes. There is no reason at all to believe in such pathological initial conditions.'

Very powerful 'global' theorems and results on the nature and existence of singularities have been developed by Penrose, Hawking, Geroch, and others, in some truly remarkable work. 'Global' laws concerning black holes, formulated by Bardeen, Hawking, and Carter and known as the 'Four Laws of Black Hole Mechanics' bear interesting analogies to the laws of thermodynamics. The second law, for example, states that the surface area of *any* black hole can never decrease with time. Since a black hole has an event horizon, one may speak of its area of cross section. This surface area is a two-dimensional surface, and like the surface area of a sphere of radius  $r$ ,  $4\pi r^2$ , the surface area of a non-rotating black hole is given by  $4\pi (2MG/c^2)^2$ . This surface area of a black hole has a close analogy with the *entropy* of an isolated system, and it is worthwhile discussing entropy rather briefly in order to see how the analogy arises.

To define entropy statistically, consider an isolated system whose energy is known to within a certain small range, and let

there be  $n$  states accessible to the system at this energy. In equilibrium, the  $n$  states are equally probable, and the entropy  $V$  is given by  $V = k \log n$  (log to the base  $e$  – natural logarithm) where  $k$  is Boltzmann's constant. In plain words, that is, the entropy is a measure of the amount of disorder in the system. As an illustrative example, suppose we start from an exceptional and improbable structure in the system, artificially built by the experimenter (there will be few states corresponding to this structure – small value of  $n$ ). Left to itself, this unstable structure will evolve toward more probable and more stable structures, and the greater will be the number of states in which the system can be. The probability of the system tending toward more stable structures increases, with a resulting increase in entropy. The important point to note is that the entropy of an isolated system can never decrease with time.

Since the entropy of an isolated system and the surface area of any black hole can never decrease with time, the analogy between the second law of black hole mechanics and that of thermodynamics is established.

Classical general relativity considers the space-time manifold as a deterministic structure, completely well defined down to arbitrary small distances. On the other hand, quantum geometrodynamics (quantum general relativity) predicts violent fluctuations in the geometry at distances of the order of the Planck length ( $1.616 \times 10^{-33}$  cm). The prediction of gravitational collapse has been derived from the classical form of general relativity, whereas the situation near the singularity might very well be profoundly modified by quantum effects.

In the world of quantum physics, one cannot specify both a dynamic variable (position, say) and its time rate of change (velocity). By the uncertainty principle in quantum theory, as the uncertainty of position tends to zero, so the uncertainty in velocity or alternatively momentum becomes infinite. Given the precise 3 geometry (descriptors of momentary configuration) at one instant, one cannot also know at that instant the time rate of change of the 3 geometry. In other words, given the relativistic

field coordinate, one cannot know the relativistic field momentum. Wheeler notes:

'The uncertainty principle thus deprives one of any way whatsoever to predict, or even to give meaning to, "the deterministic classical history of space evolving with time". That object which is central to all of classical general relativity, the four dimensional space-time geometry, simply does not exist, except in a classical approximation.'

Whereas the term space-time is used to describe the totality of all coordinate points (three spatial, one time) or 'events', superspace is the totality of all three geometries. It should be noted that whereas the term space-time only makes sense in the classical level, superspace makes sense at both the classical and quantum levels. For, specify a 3 geometry, and give its time rate of change. In the context of classical physics, this will determine under typical circumstances the entire 4 dimensional space-time geometry. Space-time may be described as a classical leaf of history slicing through superspace.

Wheeler has suggested that whenever space-time becomes very highly curved, as it is towards the centre of a black hole, the gravitational field must be quantized. Thus, nature may avoid the singularity of collapse by changing completely, near the singularity, the laws of physics. In Rutherford's model of the atom, for example, no classical reason could be provided to prevent negatively charged electrons in orbit about the positively charged nucleus from spiralling in toward the nucleus, until in 1913 Bohr made the *ad hoc* assumption that only a quantization of the energy states of the atom would save it from destruction. A complete quantum theory of gravitation has been sought for, but as yet without success.

Let us turn our attention to the observational aspect of black holes. The most promising candidate is the X-ray system Cygnus X-1. Recall that the general relativistic two-body problem remains unsolved: observational arguments for the existence of

black holes in binary systems differ, of course, from system to system, but the central factor concerns the mass of the unseen secondary obtained using the classical mass function, together with observational evidence that the (unseen) object is indeed compact, and not, for example, a bloated red star whose light is hidden by the light of the primary. In X-ray sources identified with binary systems, the problem is thus to interpret X-ray eclipses and optical Döppler Effects to estimate the secondary's mass and size.

Hayakawa and Matsuoko were, in 1964, the first to propose that X-rays could be produced by accretion of gas in close binary systems. They discussed accretion, not on to compact companions, but rather accretion into the atmosphere of a normal companion star, with the formation of a hot-shock front. In 1966, Novikov and Zel'dovich, together with Shklovsky in 1967, were the first to point out that accretion on to neutron stars and black holes in binary systems should produce X-rays. The very significant role of the angular momentum of the gas in binary accretion was emphasized by Prendergast and Burbidge. Models of disk accretion on to neutron stars and black holes were computed by Pringle and Rees as well as by Shakura and Sunyaev in 1972. All these binary accretion models were Newtonian. As an illustrative example of accretion in the Newtonian theory, let us compute the amount of energy produced by matter accreting on to the Sun, a white dwarf, neutron star, and black hole. The final kinetic energy required by material of mass  $m$  falling on to the surface of a star of mass  $M$  and radius  $R$  is given by the simple Newtonian formula  $GMm/R$ . In the following table, the second column entitled 'Mass' is in units of solar mass; K.E. is the kinetic energy (in millions of electron volts – an electron volt is the kinetic energy acquired by an electron which is accelerated through an electric potential of one volt; one electron volt is  $1.6 \times 10^{-12}$  ergs) acquired by a single hydrogen atom falling to the object's surface; finally, the fourth column entitled 'Mass fraction' is the fraction of a solar mass per year required to produce a typical X-ray source's output of  $10^{38}$  ergs per second.

## BLACK HOLES

|                 | <i>Radius<br/>(in km)</i> | <i>Mass</i> | <i>K.E.</i> | <i>Mass<br/>Fraction</i> |
|-----------------|---------------------------|-------------|-------------|--------------------------|
| 1. Sun          | 700,000                   | 1           | 0.002       | $10^{-5}$                |
| 2. White Dwarf  | 10,000                    | 1           | 0.1         | $10^{-8}$                |
| 3. Neutron Star | 10                        | 1           | 100         | $10^{-11}$               |
| 4. Black hole   | 4                         | 10          | 1,000       | $10^{-12}$               |

The great efficiency of a neutron star or black hole in producing X-rays through the accretion process is immediately evident from this table.

Thorne, Novikov, Polnarev, and Sunyaev have recently computed the effects of General Relativity on the inner regions of the accreting disk.

Returning to Cygnus X-1, both the weak variable radio source and X-ray source in the position error box of Cygnus X-1 are believed to be associated with the spectroscopic binary star HDE 226868, which has a period of 5.6 days. The Cygnus X-1 source does not have periodic X-ray occultations, so its identification as the companion of the optical star HDE 226868 could not be made directly. In April 1971, however, the radio emission increased by a factor of at least four, while the low energy X-ray intensity decreased by a factor of three. Although there were uncertainties of the X-ray source, the radio position could be measured with a precision of about 3 seconds of arc. This position agreed with that of the 8.9 magnitude (V band) star HDE 226868. At the August 1974 meeting of the American Astronomical Society, Kellogg spoke on Cygnus X-1, and said that the only model which fits the observational data consists of a distorted primary from which matter flows into a black hole secondary, having a mass of 10 to 15 solar masses. He pointed out that theoretical studies revealed that the system could neither be a triple star nor an ordinary binary with a hot spot on the primary or secondary. Hydrogen and ionized helium (He II, wavelength 4686 Ångströms) emission lines detected in the optical spectrum originated from the mass flow bridge, and X-rays from gases disappearing into the black

hole. Photometric variations would then be due to the tidal distortion of the O-star by the invisible secondary as they rotated about a common centre of mass.

In the words of Misner, Thorne, and Wheeler:

'No longer is General Relativity "a theorists' Paradise, but an experimentalist's Hell". General Relativity has emerged from each of its tests unscathed – a remarkable (1976) tribute to the 1915 genius of Albert Einstein.'

That the search for black holes in binary systems is an experimentalist's Hell, is, I think astrophysicists would agree, no underestimation!

There is no way to avoid a massive secondary in Cygnus X-1, provided the identification of the O-star is assumed. Paczynski has pointed out that the mass or luminosity of the optically observed component cannot be uniquely determined from its spectral type, but is subject to large uncertainties for a star bathed in a strong X-ray flux from its companion.

Lynden-Bell, in 1969, argued that galaxies might have super-massive black holes at their centres, and analysed disk type accretion on to such holes. Interest in gravitational collapse was revived by the discovery of quasars, and their apparently enormous energy requirements. Lynden-Bell has advanced the hypothesis that accretion of matter on to central black holes might produce quasars. It is important to note that a particle in orbit about a Schwarzschild black hole can emit only about 5.7 per cent of its mass as gravitational radiation before it falls into the hole. However, for a particle co-rotating with a Kerr black hole, as much as 42.3 per cent of its mass can be radiated as gravitational energy.

Let us, finally, briefly consider the problem of the missing mass. If Einstein's closure boundary condition of the Universe is correct, then it can be shown that the density of mass-energy must exceed a certain lower value of  $5 \times 10^{-30}$ , grams per cubic centimetre if the present value of Hubble's 'constant' is taken to be 55 km/sec/Mpc. Needless to say, it is an extremely difficult and formidable

task to measure the value of the mean density of matter in the Universe today. Oort gives the density of luminous matter as about  $2 \times 10^{-31}$  g/cm<sup>3</sup>, yielding a ratio of the density of luminous matter/theoretically computed density of 0.04 (if there were no missing mass, this ratio would, of course, be unity). Noonan, Weinberg, and Shapiro gives as estimates of this ratio the values 0.016, 0.028, and 0.010. Thus, according to Noonan's estimate, the density of observable matter is only 16/1000 that of the theoretically computed value. Where is the missing mass? It has been speculated that the missing mass is in the form of black holes, but it should be remembered that the study of intergalactic matter is only in its earliest stages.

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I wish to thank Professor G. F. R. Ellis most sincerely for discussions during my visit to the University of Cape Town, and Professor A. H. Jarrett for his kindness and hospitality at the University of the Orange Free State and Boyden Observatory. This is greatly appreciated.

## **Recent Advances in Astronomy**

PATRICK MOORE

Inevitably the *Yearbook* has to go to press well before publication day, so that I cannot deal with events which will certainly happen during the second half of 1975. I can, however, mention one major event which took place in mid-July: the link-up in space between an Apollo space-craft and a Russian Soyuz. The meeting actually occurred on 17 July, and it is worth recording the names of the space men who took part: Stafford, Brand and Slayton for America, Leonov and Kubasov for Russia.

This was the first real co-operation beyond Earth, and was of tremendous significance. Both vehicles were modified to make the link practicable, and the whole programme went through without a hitch. Let us hope that it is the prelude to true understanding not only in space, but also on the surface of the Earth.

The next major space development will be the launching of the U.S. Viking, in August 1975. Two probes are due to be sent towards Mars, and should make soft landings there in the middle of 1976. On 4 July, Viking 1 is scheduled to come down in the Martian region known as Chryse, and a month later its successor will land in the rather less well-known region of Cydonia. The scientific programmes for both vehicles are extensive, but of course one question dominates all others: Is there life of any kind on Mars? The brilliant-brained canal-builders of Percival

## RECENT ADVANCES IN ASTRONOMY

Lowell and his colleagues have been relegated to the pages of science-fiction novels; but hostile though it undoubtedly is, Mars more nearly resembles the Earth than any other planet, and we cannot yet dismiss it as sterile. The discovery of any primitive organisms there, either in fossil or in living form, would cause a complete upheaval in scientific outlook. The chances appear to be slender, but they are not nil, and if the Vikings are successful one of the most fascinating controversies in astronomy will be cleared up within the next year. Incidentally, the Russians have launched two further probes to Venus, which are probably intended to parachute down through the atmosphere of that decidedly peculiar planet and send back further data. The arrival date has been given as October 1975, so that the results should be known by the time that the *Yearbook* is published.

Meantime, much has been learned from the two Pioneers to Jupiter, the last of which made its pass at the end of 1974. For instance we now know positively that water exists there – not too much of it, but a significant amount. Also, the aspect near the Jovian poles differs from that in the lower latitudes. The belts are lower than the zones, and are perceptibly warmer, but a major surprise has been the lack of any significant difference in temperature between equator and pole. According to one theory, this must mean that the polar regions are being more strongly warmed by the Jovian internal heat-source. This would lead to convection currents and a generally more unstable picture – which is precisely what the Pioneer photographs show. Of course, the results so far are somewhat tentative, and different experts have different ideas, but certainly Jupiter is proving to be even more fascinating than had been expected – quite apart from its remarkable satellite system.

During the past year Greenwich Observatory has celebrated its tercentenary, and there have been many celebrations to mark the event. Since it was established in 1675, with the Rev. John Flamsteed in charge, Greenwich has had an eventful and not always a smooth history; but it has retained its position as the 'timekeeping centre' of the world, and the amount of research

work carried out there is tremendous. However, there have been some departures from tradition. In particular, the Director of the Royal Greenwich Observatory is now no longer the Astronomer Royal. On the retirement of Sir Richard Woolley, Mrs Margaret Burbidge succeeded him at Greenwich, while the great Cambridge radio astronomer, Sir Martin Ryle, became Astronomer Royal. Mrs Burbidge soon resigned, and at Greenwich Dr Alan Hunter took over; when he too retires, on 31 December 1975, Professor F. Graham Smith will become Director – so that both the senior posts in British astronomy are now filled by radio astronomers.

There is also the question of the 98-inch Isaac Newton telescope, usually called the INT for short. At its site at Herstmonceux it can seldom be used to full capacity, because of the relatively unfavourable climatic conditions, and there has long been talk of moving it away from England. Plans for the new Northern Hemisphere Observatory have now been approved, though the site has not yet been finally selected; La Palma, in the Canary Islands, is a strong possibility. In any event, the INT will go to the new Observatory, where it will be joined by a new 180-inch reflector as well as various smaller instruments; Herstmonceux will seem strange without it. Also, the 28-inch refractor has been moved back to Old Greenwich, and has been installed in a dome which looks superficially very like the old 'onion dome' which suffered so badly during the war – though the new dome is made of materials rather stronger than the old paper-mâché.

What is generally called 'invisible astronomy' is coming more and more to the fore, and the 60-inch infra-red telescope on Mount Teide, on Tenerife, is now in full operation. Funds have now been approved for a new 150-inch infra-red telescope, which will be set up in Hawaii and will be British-operated. Theoretical work carried out with regard to infra-red objects is of immense interest. There is, for instance, Becklin's Object in the Orion Nebula, which cannot be seen visually because of the intervening material. It may be a very young star, but Dr David

## RECENT ADVANCES IN ASTRONOMY

Allen – well known to all *Yearbook* readers, and currently working in Australia – believes it to be an immensely luminous star, perhaps a million Sun-power, which is permanently concealed by the surrounding nebular material.

Then, too, there is X-ray astronomy, in which there have been exciting developments due largely to equipment carried in the British satellite Ariel. In December, Ariel detected a new and very powerful source close to the well-known Centaurus emitter; since it reached its maximum power on Christmas Day, 1974, the temptation to call it Cen-Xmas was really too good to be missed! Predictably it faded, and the same was true of a second 'X-ray nova' which appeared close to the Crab Nebula, and which during May 1975 was even more powerful than the Crab itself. It is a coincidence that these two sources burst forth so close to famous X-ray objects, but astronomers are unanimous in saying that it is a coincidence and nothing more. The second source was given the unofficial nickname of 'Fresh Crab'. . .

Surprisingly, these transient sources 'flashed' not in seconds, but in periods of minutes; and this raised new problems. Theoretical conditions seem to rule out the idea of a rotating star, and a binary system seems to be the only possible answer. The main component cannot be a giant, and it seems that both stars involved must be very small indeed. They could be White Dwarfs, neutron stars, or even – just possibly – Black Holes. The distance between the two components must be of the order of no more than 10,000 to 50,000 miles.

It has also been found that X-rays are coming from the region of the galactic centre, and that the source coincides with that of the famous radio waves. It is just possible that we may be detecting emissions from a 'supermassive' object, much too big to be a star of normal kind, but this is little more than speculation as yet, and further data are needed.

Meanwhile, the seemingly endless argument about the past history of the universe goes on. During the 1950s astronomers such as Bondi, Gold, and Hoyle were still advocating the steady-state theory, and even today the theory is not dead, but it has

fallen from general favour and recently it has received yet another blow. The quasar 3C-48 is not among the most remote known, and it is surrounded by a wispy nebula. Spectroscopic studies of the nebula show a red shift marginally greater than that of the quasar. If the red shift were due to the gravitational pull of the massive body, then the shift should decrease with increasing distance from the body – since the pull would become less. This does not happen, and it follows that the red shift is due to the Doppler effect; the quasar really is immensely remote, and racing away from us at an almost incredible speed.

This is in conflict with the steady-state theory, because if the red shifts are Doppler effects all the quasars must have existed a very long time ago – their light takes thousands of millions of years to reach us, and there are no quasars close to us. Therefore, the universe has changed markedly since the quasar epoch.

Recently I looked back at the first issue of the *Yearbook*, which came out in 1962. In those days objects such as quasars, pulsars, and Black Holes were not only unknown, but also mainly unsuspected; the idea of landing men on the Moon was still widely ridiculed, and space-flight was in its infancy. The first successful planetary probe, Mariner 2, by-passed Venus in that year, but Mars was still out of reach, and was believed to be a world with a reasonably dense nitrogen-rich atmosphere and wide tracts of primitive vegetation. The progress of astronomy has been more rapid during the past few years than at any time in the history of science, and no doubt there will be more spectacular developments before 1976 draws to its end.

**PART THREE**

## **For Stellar Observers**

# Easy Double Stars

PATRICK MOORE

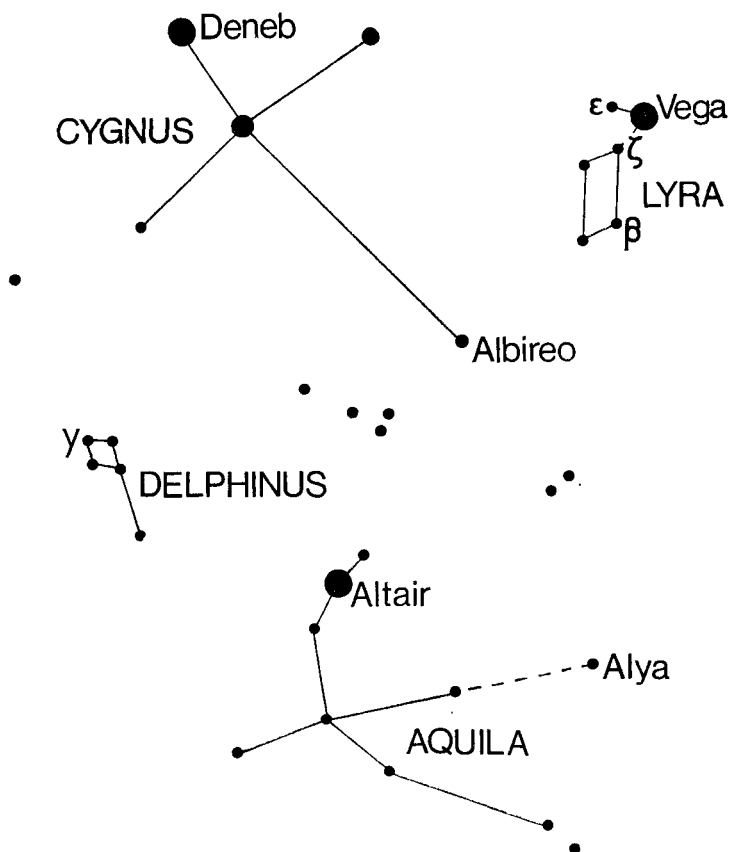
Among amateur astronomers, double stars are less carefully studied than variables. The reason is simple enough. With a variable star, the observer can carry out really useful work by making eye-estimates; it is possible to achieve an accuracy of a tenth of a magnitude, which is good enough for some kinds of stars. If, however, double-star separations and position angles are to be measured, it is necessary to use a fairly large, accurately driven telescope together with a micrometer; and even with proper equipment the work needs a tremendous amount of practice before any reasonably reliable results can be obtained.

There is certainly scope for re-measurement of some of the classical pairs. For instance, many books state that Castor in Gemini is very wide and easy. So it used to be; but it is a binary with a period of 380 years, and it is now closing, so that it is certainly not striking when seen through a small telescope. When I first began looking at double stars (around 1930) Gamma Virginis was one of the most spectacular of all pairs; but it, too, is now closing, and by the turn of the century it will appear single in most amateur-sized telescopes. Some of the figures published in popular books are very out of date.

In the present article I do not propose to become at all technical. My aim is to give details about some of the really easy pairs which can be looked at with modest equipment. Neither am I making any attempt to be exhaustive; I give merely a personal selection of pairs.

A few are, of course, separable with the naked eye; keen-sighted people can split the two main components of the famous multiple

star Epsilon Lyræ, near Vega, where the separation is 208". In this case the components are physically connected, and each is itself double. With Alpha Capricorni, the separation is even greater (376") and both components are of about the fourth magnitude (3.7 and 4.3 respectively). Much more difficult to the naked-eye observer is Nu Draconis, with two equal components (magnitudes 4.5) separated by 62". We must also try to define a 'double star'; the components of, for instance, Theta Tauri in



the Hyades, or Delta and Mu in the far southern constellation of Grus (the Crane) are too wide to be classed as genuine pairs. So, in theory, is the Mizar-Alcor pair in Ursa Major.

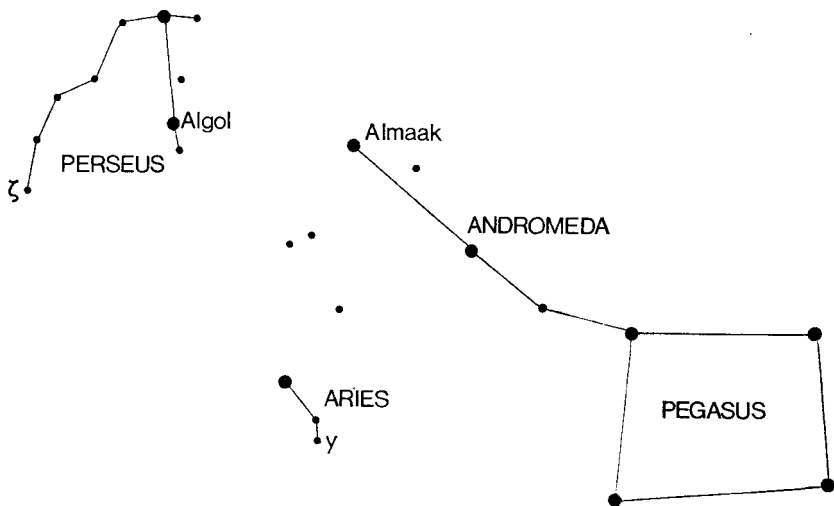
Yet Mizar itself provides a good starting-object for the double-star enthusiast. It is made up of two white stars of magnitudes 2.2 and 3.9, separated by  $14''.5$ , so that any telescope will split it; with a low power Alcor is in the same field, and there is another star between Alcor and the Mizar pair. This star is not a member of the system, and has, incidentally, been suspected of variability, though the evidence is very meagre.

Equally easy is Albireo or Beta Cygni, the faintest of the stars making up the cross of the Swan. In my view this is much the most beautiful pair in the whole sky. The components are of magnitudes 3 and 5, and the separation is over  $34''$ , so that virtually any telescope will suffice, but the glory of Albireo lies in its colouration. The primary is golden-yellow, while the secondary is bluish or greenish – different people describe it in different ways. Even good binoculars will show the two components quite well. The two members are genuinely associated, but they are so far apart that their revolution period is immensely long, and all we can really say is that they share a common motion through space. Albireo is, incidentally, very remote and luminous. If it lay at the 'standard distance' of 10 parsecs ( $32.6$  light-years) it would shine as brightly as Jupiter.

In the same part of the sky we have several more very easy pairs. Lyra is rich in them. Epsilon has already been mentioned; both components can be split with a modest aperture, though the separations are less than  $3''$  in each case, and a reasonable magnification is needed. Zeta Lyræ, nearby, has components of magnitudes 4.3 and 5.9 separated by almost  $44''$ , and presents no difficulty at all; and the celebrated eclipsing star Beta Lyræ has an eighth-magnitude companion about  $47''$ . In the Dolphin, again in the same part of the sky, we find Gamma Delphini (4.5 and 5.5; separation over  $10''$ ) which again is extremely easy. It is said that the primary is yellowish and the secondary greenish, though I admit that to me the colours are distinctly elusive.

If you want a really wide, easy pair, then look at Theta Serpentis, still sometimes known by its old proper name of Alya. It lies close to the line of stars in Aquila of which the famous Cepheid variable Eta Aquilæ is the central member. The two components of Alya are exactly equal at magnitude 4.5, and the wide separation of 23" makes it a fine object for a very small telescope.

Another pair in which the components are almost identical is Gamma Arietis, the faintest of the three stars making up the main pattern of the Ram. Each component is rather above the fifth magnitude, and the separation is 8", so that a small telescope will give a good view of these celestial twins. Also very easy is Gamma Andromedæ or Almaak; the second-magnitude orange primary has a bluish companion of magnitude 5. The separation is 10"; and apart from Albireo, Almaak is probably the best example of a double with contrasting hues. Owners of large telescopes will be able to see that the companion is itself double, but the separation is, of course, much less; it was 0".6 in 1971, but is now closing, as the star is a binary with a period of 61



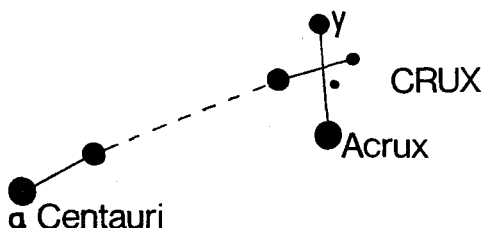
years. Two of the bright stars in the adjacent constellation of Perseus have faint, distant companions; the eclipsing variable Algol (companion magnitude 10.5) and Zeta Persei (2.9, 9.4; 13") which are good tests for very small apertures.

Let us now turn back to Gamma Virginis or Arich, which used to be such a fine pair. Each component is of magnitude 3.6; I have never been able to tell the slightest difference between them. The present separation is over 4", so that a small telescope will still split the pair; the least separation will not occur until A.D. 2016, so that there is no urgent need to look at Arich before it appears single! Quite different is Gamma Leonis, in the Sickle. Here we have components of magnitudes 2.6 and 3.8, again with different colours, and a separation of 4".3. It, too, is a binary, but the period amounts to 407 years, and at present the separation is actually increasing. With Castor, the senior though fainter member of the Twins, the period is 350 years; one component is of the second magnitude and the other of the third. There is a much fainter component, Castor C (magnitude 9.5) at 73".4. All three members of the Castor system are very close binaries, so that we have a true cosmical family. Castor C is an eclipsing pair, and is alternatively known as YY Geminorum.

Two famous red stars have greenish or bluish companions; Antares in Scorpio (magnitudes 1.0 and 5.1; 3") and Rasalgethi or Alpha Herculis (separation 4".6, companion magnitude 5.4; the primary varies between magnitudes 3 and 4). Both pairs are fairly easy. With the Pole Star, the white, second-magnitude primary has a ninth-magnitude companion at 18".3. Rigel, the leader of Orion, has a seventh-magnitude companion at 9". The companion is not so obvious as might be thought, because it is so overpowered by Rigel itself. It is said to be a test for a 2-inch refractor, but frankly I always find it difficult with any aperture below 3 inches, though other observers will doubtless disagree. Another pair said to be a test for a 2-inch is Epsilon Boötis, not far from Arcturus (2.7, 5.1; 3"). Again we have a yellowish primary with a companion which many people describe as bluish.

All these pairs are accessible from Europe and the United

States, but there are some superb double stars in the far south. Alpha Centauri, the brighter of the two pointers to the Southern Cross, is probably the best example. The magnitudes are 0.3 and 1.7, so that when seen shining together they make Alpha Centauri the brightest star in the sky apart from Sirius and Canopus. The period is 80 years, so that both separation and position angle alter quickly; the average separation is about 4", so that the view through a small telescope is spectacular. Of course, Alpha Centauri is the closest of all the bright stars; Proxima, its faint companion, is beyond the reach of a small aperture – and is none too easy to identify even with a powerful telescope.



Acrux, leader of the Cross, is made up of two main components (1.6, 2.1; 4".7) and there is also a third star in the field, so that the pair is comparable in splendour with Alpha Centauri. Gamma Crucis has a seventh-magnitude companion at 111"; this is an optical pair, not a binary. Gamma is always worth looking at, since it is a Red Giant, and its colour contrasts sharply with the glittering whiteness of the other main stars in the Southern Cross.

Three more fine southern pairs are worthy of mention here. Gamma Velorum, in the sails of the old ship Argo, is of magnitude 2.2; it has a 5th-magnitude companion at 41", and is very easy with a modest telescope. So, too, is Theta Eridani or Acamar, the 'Last in the River' (3.4, 4.4; 8".5), which is particularly interesting inasmuch as Ptolemy and other observers of ancient times ranked it as of the first magnitude; either they were in error, or else Acamar has faded – the present combined magnitude as

## EASY DOUBLE STARS

seen with the naked eye is only 3.1. Finally, we have Beta Tucanæ, where the two equal components, each of magnitude 4.5, are separated by 27". There is a fifth-magnitude star in the same field, and all three members of the group are themselves very close, difficult binaries. Tucana itself is not too easy to identify, but the presence in it of most of the Small Magellanic Cloud is a help – and also in the constellation we have the globular cluster 47 Tucanæ, the finest in the whole sky apart from Omega Centauri.

These, then, are some of the doubles within range of the casual observer equipped with a small telescope. I repeat that the list is anything but exhaustive; but if you take an adequate star map and a list of suitable objects, you will be able to locate a great many of these fascinating stellar pairs.

# Some Interesting Telescopic Variable Stars

| Star              | R.A. |    | Dec. |    | Mag. range | Period, days | Remarks         |
|-------------------|------|----|------|----|------------|--------------|-----------------|
|                   | h    | m  | °    | '  |            |              |                 |
| R Andromedæ       | 0    | 22 | +38  | 18 | 6.1-14.9   | 409          |                 |
| W Andromedæ       | 2    | 14 | +44  | 4  | 6.7-14.5   | 397          |                 |
| R Aquilæ          | 19   | 4  | +8   | 9  | 5.7-12.0   | 300          |                 |
| R Arietis         | 2    | 13 | +24  | 50 | 7.5-13.7   | 189          |                 |
| R Aurigæ          | 5    | 13 | +53  | 32 | 6.7-13.7   | 459          |                 |
| R Boötis          | 14   | 35 | +26  | 57 | 6.7-12.8   | 223          |                 |
| R Cassiopeiæ      | 23   | 56 | +51  | 6  | 5.5-13.0   | 431          |                 |
| T Cassiopeiæ      | 0    | 20 | +55  | 31 | 7.3-12.4   | 445          |                 |
| T Cephei          | 21   | 9  | +68  | 17 | 5.4-11.0   | 390          |                 |
| Omicron Ceti      | 2    | 17 | -3   | 12 | 2.0-10.1   | 331          | Mira.           |
| R Coronæ Borealis | 15   | 46 | +28  | 18 | 5.8-14.8   | -            | Irregular       |
| W Coronæ Borealis | 16   | 36 | +37  | 55 | 7.8-14.3   | 238          |                 |
| R Cygni           | 19   | 35 | +50  | 5  | 6.5-14.2   | 426          |                 |
| U Cygni           | 20   | 18 | +47  | 44 | 6.7-11.4   | 465          |                 |
| W Cygni           | 21   | 34 | +45  | 9  | 5.0-7.6    | 131          |                 |
| SS Cygni          | 21   | 41 | +43  | 21 | 8.2-12.1   | -            | Irregular.      |
| Chi Cygni         | 19   | 49 | +32  | 47 | 3.3-14.2   | 407          | Near Eta.       |
| R Draconis        | 16   | 32 | +66  | 52 | 6.9-13.0   | 246          |                 |
| R Geminorum       | 7    | 4  | +22  | 47 | 6.0-14.0   | 370          |                 |
| U Geminorum       | 7    | 52 | +22  | 8  | 8.8-14.4   | -            | Irregular       |
| S Herculis        | 16   | 50 | +15  | 2  | 7.0-13.8   | 307          |                 |
| U Herculis        | 16   | 23 | +19  | 0  | 7.0-13.4   | 406          |                 |
| R Hydræ           | 13   | 27 | -23  | 1  | 4.0-10.0   | 386          |                 |
| R Leonis          | 9    | 45 | +11  | 40 | 5.4-10.5   | 313          | Near 18, 19.    |
| X Leonis          | 9    | 48 | +12  | 7  | 12.0-15.1  | -            | Irregular       |
| R Leporis         | 4    | 57 | -14  | 53 | 5.9-10.5   | 432          | (U Gem type).   |
| R Lyncis          | 6    | 57 | +55  | 24 | 7.2-14.0   | 379          | 'Crimson star.' |
| W Lyrae           | 18   | 13 | +36  | 39 | 7.9-13.0   | 196          |                 |
| HR Delphini       | 20   | 40 | +18  | 58 | 3.6-?      | -            | Nova, 1967.     |
| LV Vulpeculæ      | 19   | 45 | +27  | 2  | 4.8-?      | -            | Nova, 1968.     |
| U Orionis         | 5    | 53 | +20  | 10 | 5.3-12.6   | 372          |                 |
| R Pegasi          | 23   | 4  | +10  | 16 | 7.1-13.8   | 378          |                 |
| S Persei          | 2    | 19 | +58  | 22 | 7.9-11.1   | 810          | Semi-regular.   |
| R Scuti           | 18   | 45 | -5   | 46 | 5.0-8.4    | 144          |                 |
| R Serpentis       | 15   | 48 | +15  | 17 | 5.7-14.4   | 357          |                 |
| SU Tauri          | 5    | 46 | +19  | 3  | 9.2-16.0   | -            | Irregular       |
|                   |      |    |      |    |            |              | (R CrB type).   |
| R Ursæ Majoris    | 10   | 41 | +69  | 2  | 6.7-13.4   | 302          |                 |
| S Ursæ Majoris    | 12   | 42 | +61  | 22 | 7.4-12.3   | 226          |                 |
| T Ursæ Majoris    | 12   | 34 | +59  | 46 | 6.6-13.4   | 257          |                 |
| S Virginis        | 13   | 30 | -6   | 56 | 6.3-13.2   | 380          |                 |
| R Vulpeculæ       | 21   | 2  | +23  | 38 | 8.1-12.6   | 137          |                 |

## Some Interesting Double Stars

The pairs listed below are well-known objects, and all the primaries are easily visible with the naked eye, so that right ascensions and declinations are not given. Most can be seen with a 3-inch refractor, and all with a 4-inch under good conditions, while quite a number can be separated with smaller telescopes, and a few (such as Alpha Capricorni) with the naked eye. Yet other pairs, such as Mizar-Alcor in Ursa Major and Theta Tauri in the Hyades, are regarded as too wide to be regarded as bona-fide doubles!

| Name                 | Magnitudes | Separation,* | Position angle, deg. | Remarks                                                              |
|----------------------|------------|--------------|----------------------|----------------------------------------------------------------------|
| Gamma Andromedæ      | 3.0, 5.0   |              | 060                  | Yellow, blue. B is again double (0".4) but needs a larger telescope. |
| Zeta Aquarii         | 4.4, 4.6   | 2.6          | 291                  | Becoming more difficult.                                             |
| Gamma Arietis        | 4.2, 4.4   | 8            | 000                  | Very easy.                                                           |
| Theta Aurigæ         | 2.7, 7.2   | 3            | 330                  | Stiff test for 3 in. OG.                                             |
| Delta Boötis         | 3.2, 7.4   | 105          | 079                  | Fixed.                                                               |
| Epsilon Boötis       | 3.0, 6.3   | 2.8          | 340                  | Yellow, blue. Fine pair.                                             |
| Kappa Boötis         | 5.1, 7.2   | 13           | 237                  | Easy.                                                                |
| Zeta Cancri          | 5.6, 6.1   | 5.6          | 082                  |                                                                      |
| Iota Cancri          | 4.4, 6.5   | 31           | 307                  | Easy. Yellow, blue.                                                  |
| Alpha Canum Venat.   | 3.2, 5.7   | 20           | 228                  | Yellowish, bluish. Easy.                                             |
| Alpha Capricorni     | 3.2, 4.2   | 376          | 291                  | Naked-eye pair. Alpha again double.                                  |
| Eta Cassiopeie       | 3.7, 7.4   | 11           | 298                  | Creamy, bluish. Easy.                                                |
| Beta Cephei          | 3.3, 8.0   | 14           | 250                  |                                                                      |
| Delta Cephei         | var, 7.5   | 41           | 192                  | Very easy.                                                           |
| Xi Cephei            | 4.7, 6.5   | 6            | 270                  | Reasonably easy.                                                     |
| Gamma Ceti           | 3.7, 6.2   | 3            | 300                  | Not too easy.                                                        |
| Zeta Coronæ Borealis | 4.0, 4.9   | 6.3          | 304                  |                                                                      |
| Delta Corvi          | 3.0, 8.5   | 24           | 212                  |                                                                      |
| Beta Cygni           | 3.0, 5.3   | 35           | 055                  | Yellow, green. Glorious.                                             |
| 61 Cygni             | 5.3, 5.9   | 25           | 150                  |                                                                      |
| Gamma Delphini       | 4.0, 5.0   | 10           | 265                  | Yellow, greenish. Easy.                                              |
| Nu Draconis          | 4.6, 4.6   | 62           | 312                  | Naked-eye pair.                                                      |
| Alpha Geminorum      | 2.0, 2.8   | 2            | 151                  | Castor. Becoming easier.                                             |
| Delta Geminorum      | 3.2, 8.2   | 6.5          | 120                  |                                                                      |
| Alpha Herculis       | var, 6.1   | 4.5          | 110                  | Red, green.                                                          |
| Delta Herculis       | 3.0, 7.5   | 11           | 208                  | Optical double.                                                      |
| Zeta Herculis        | 3.0, 6.5   | 1.4          | 300                  | Fine, rapid binary.                                                  |
| Gamma Leonis         | 2.6, 3.8   | 4.3          | 121                  | Binary; period 400 years.                                            |
| Alpha Lyre           | 0.0, 10.5  | 60           | 180                  | Vega. Optical; B faint.                                              |
| Epsilon Lyre         | 4.6, 6.3   | 3            | 005                  | Quadruple. Both pairs                                                |
|                      | 4.9, 5.2   | 2.3          | 111                  | separable in 3 in. OG                                                |
| Zeta Lyre            | 4.2, 5.5   | 44           | 150                  | Fixed. Easy double.                                                  |
| Beta Orionis         | 0.1, 6.7   | 9.5          | 205                  | Rigel. Can be split with 3 in.                                       |
| Iota Orionis         | 3.2, 7.3   | 11           | 140                  |                                                                      |

## SOME INTERESTING CLUSTERS AND NEBULÆ

| <i>Name</i>        | <i>Magnitudes</i>     | <i>Separation,*</i> | <i>Position<br/>angle, deg.</i> | <i>Remarks</i>                                            |
|--------------------|-----------------------|---------------------|---------------------------------|-----------------------------------------------------------|
| Theta Orionis      | 6.0, 7.0<br>7.5, 8.0  |                     |                                 | The famous Trapezium in M.42                              |
| Sigma Orionis      | 4.0, 7.0<br>7.5, 10.0 | 11.1<br>12.9        | 236<br>085                      | Quadruple. D is rather faint in small apertures.          |
| Zeta Orionis       | 1.9, 5.0              | 3                   | 160                             |                                                           |
| Eta Persei         | 4.0, 8.5              | 8.5                 | 300                             | Yellow, bluish.                                           |
| Alpha Piscium      | 4.3, 5.3              | 1.9                 | 291                             |                                                           |
| Alpha Scorpii      | 0.9, 6.8              | 3                   | 275                             | Antares, Red. green.                                      |
| Nu Scorpii         | 4.2, 6.5              | 42                  | 336                             |                                                           |
| Theta Serpentis    | 4.1, 4.1              | 23                  | 103                             | Very easy.                                                |
| Alpha Tauri        | 0.8, 11.2             | 130                 | 032                             | Aldebaran. Wide, but B is very faint in small telescopes. |
| Zeta Ursæ Majoris  | 2.3, 4.2              | 14.5                | 150                             | Mizar. Very easy. Naked eye pair with Alcor.              |
| Alpha Ursæ Minoris | 2.0, 9.0              | 18.3                | 217                             | Polaris. Can be seen with 3 in.                           |
| Gamma Virginis     | 3.6, 3.7              | 4.8                 | 305                             | Binary; period 180 yrs. Closing.                          |
| Theta Virginis     | 4.0, 9.0              | 7                   | 340                             | Not too easy.                                             |

## Some Interesting Clusters and Nebulæ

| <i>Object</i>         | <i>R.A.</i> | <i>Dec.</i>  | <i>Remarks</i>                                                           |
|-----------------------|-------------|--------------|--------------------------------------------------------------------------|
|                       | <i>h m</i>  | <i>° ' "</i> |                                                                          |
| M.31 Andromedæ        | 00 40.7     | +41 05       | Great Galaxy, visible to naked eye.                                      |
| H.VIII 78 Cassiopeiæ  | 00 41.3     | +61 36       | Fine cluster, between Gamma and Kappa Cassiopeiæ.                        |
| M.33 Trianguli        | 01 31.8     | +30 28       | Spiral. Difficult with small apertures.                                  |
| H.VI 33-4 Persei      | 02 18.3     | +56 59       | Double cluster; Sword-handle.                                            |
| M.1 Tauri             | 05 32.3     | +22 00       | Crab Nebula, near Zeta Tauri.                                            |
| M.42 Orionis          | 05 33.4     | -05 24       | Great Nebula. Contains the famous Trapezium, Theta Orionis.              |
| M.35 Geminorum        | 06 06.5     | +24 21       | Open cluster near Eta Geminorum.                                         |
| H.VII 2 Monocerotis   | 06 30.7     | +04 53       | Open cluster, just visible to naked eye.                                 |
| M.41 Canis Majoris    | 06 45.5     | -20 42       | Open cluster, just visible to naked eye.                                 |
| M.44 Cancri           | 08 38       | +20 07       | Praesepe. Open cluster near Delta Cancri. Visible to naked eye.          |
| M.97 Ursæ Majoris     | 11 12.6     | +55 13       | Owl Nebula, diameter 3'. Planetary.                                      |
| M.3 Canum Venaticorum | 13 40.6     | +28 34       | Bright globular.                                                         |
| M.80 Scorpionis       | 16 14.9     | -22 53       | Globular, between Antares and Beta Scorpionis.                           |
| M.4 Scorpionis        | 16 21.5     | -26 26       | Open cluster close to Antares.                                           |
| M.13 Herculis         | 16 40       | +36 31       | Globular. Just visible to naked eye.                                     |
| M.92 Herculis         | 17 16.1     | +43 11       | Globular. Between Iota and Eta Herculis.                                 |
| M.7 Scorpionis        | 17 51.6     | -34 48       | Fine open cluster. Very low in England.                                  |
| M.23 Sagittarii       | 17 54.8     | -19 01       | Open cluster nearly 50' in diameter.                                     |
| H.VI 37 Draconis      | 17 58.6     | +66 38       | Bright Planetary.                                                        |
| M.8 Sagittarii        | 18 01.4     | -24 23       | Lagoon Nebula. Gaseous. Just visible with naked eye.                     |
| NGC 6572 Ophiuchi     | 18 10.9     | +06 50       | Bright planetary, between Beta Ophiuchi and Zeta Aquilæ.                 |
| M.17 Sagittarii       | 18 18.8     | -16 12       | Omega Nebula. Gaseous. Large and bright.                                 |
| M.11 Scuti            | 18 49.0     | -06 19       | Wild Duck. Bright open cluster.                                          |
| M.57 Lyræ             | 18 52.6     | +32 59       | Ring Nebula. Brightest of planetaries.                                   |
| M.27 Vulpeculæ        | 19 58.1     | +22 37       | Dumb-bell Nebula, near Gamma Sagittæ.                                    |
| H.IV 1 Aquarii        | 21 02.1     | -11 31       | Bright planetary near Nu Aquarii.                                        |
| M.15 Pegasi           | 21 28.3     | +12 01       | Bright globular, near Epsilon Pegasi.                                    |
| M.39 Cygni            | 21 31.0     | +48 17       | Open cluster between Deneb and Alpha Lacertæ. Well seen with low powers. |

PART FOUR

**Miscellaneous**

## Some Recent Books

*Asimov on Astronomy*, by Isaac Asimov. Macdonald & Co. A fascinating collection of essays, with a wide range – written in the inimitable Asimov manner!

*The Young Astronomer and His Telescope*, by Patrick Moore. Keith Reid Ltd. Written for the teenage enthusiast who wants to know how to start astronomy, what telescope to buy, how to set about school projects, and the prospects of a career in astronomy.

*The Planet Mars*, by E. M. Antoniadi. Keith Reid Ltd. A translation of the classic book by Antoniadi, written forty years ago but of great historical interest.

*Galileo*, by Colin Ronan. Michael Joseph Ltd. A finely illustrated account of the life and work of the first great telescopic astronomer.

*Lunar Science: a Post- Apollo View*, by S. R. Taylor. Pergamon. Excellent, lucid account, for the reader with a sound background of astronomy and geology.

## **Our Contributors**

H. G. MILES, B.E.M., B.Sc., is a lecturer at the Lanchester College of Technology, Coventry. He is the current President of the British Astronomical Association, and is also Director of its Artificial Satellite Section. He also specializes in meteor and meteorite research. He is the author of many scientific contributions, both technical and popular, and will be well known to all readers of past *Yearbooks*.

DR GARRY HUNT, of the Meteorological Office, Bracknell, is one of the world's leading experts in planetary research, and is closely concerned with the current space-probe projects, so that he makes very frequent visits to the American centres. In addition to his many technical papers he is well known for his television broadcasts.

RAMON LANE lives in Northumberland, where he has his private observatory; he concentrates almost exclusively upon solar work, and his photographic results are known all over the world.

DR DAVID A. ALLEN took his B.A. at Cambridge University in 1967, and his Ph.D. in 1971. For some years he has been carrying out his researches at the Royal Greenwich Observatory, Herstmonceux, but is now to spend some time in Australia. His recent work has been concentrated upon infra-red astronomy; telescopes used include the Palomar 200 in. and the Mount Wilson 100 in. as well as the 98 in. Isaac Newton reflector which has been at Herstmonceux.

## OUR CONTRIBUTORS

W. E. PENNELL has his observatory at Lincoln, and has earned a great reputation as an astronomical photographer, particularly in the field of stellar work. He is a Council Member of the British Astronomical Association.

DAVID L. BLOCK, a graduate of the Witwatersrand University in South Africa, has his observatory at Krugersdorp, some way from Johannesburg. Though still only twenty-one years old, he has made notable technical contributions in the field of mathematical astronomy, and has published papers in the main technical journals, including the *Quarterly Journal of the Royal Astronomical Society*. He is now concentrating upon research into Black Holes.

# Astronomical Societies in Great Britain

The advantages of joining an astronomical society are obvious enough. Full information about national and local Societies was given in the 1966 *Yearbook*; a condensed list, suitably brought up to date, is given below.

| <i>Name</i>                                  | <i>Secretarial Address</i>                                                  | <i>Yearly Subscription</i><br>\$=members under 18, or 'juniors' | <i>Meeting Time and Place</i>                                                                          |
|----------------------------------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| British Astronomical Association             | Burlington House,<br>Piccadilly,<br>London, W.1.<br>(J. L. White)           | £3.25<br>(\$£2.50)                                              | Burlington House,<br>Piccadilly<br>Last Wed. each month<br>(Oct-June)                                  |
| Irish Astronomical Association               | The Planetarium,<br>Armagh<br>(D. Beesley)                                  | £2<br>(\$£1)                                                    | Belfast<br>Fortnightly<br>Armagh<br>Monthly                                                            |
| Junior Astronomical Society                  | 58 Vaughan Gardens,<br>Ilford, Essex                                        | £1                                                              | Alliance Hall, Palmer St.,<br>WC1<br>Last Saturday Jan.,<br>April, July, Oct.<br>2.30 p.m.             |
| Aberdeen and District Astronomical Society   | 14 Abbotshall Gardens,<br>Cults, Aberdeen<br>(W. P. Cooper)                 |                                                                 | Robert-Gordon's<br>Institute of Technology,<br>St Andrew Street,<br>Aberdeen                           |
| Altrincham and District Astronomical Society | 10 Delamere Road,<br>Gatley, Cheadle, Cheshire<br>(Colin Henshaw)           | 25p                                                             | Park Road Library,<br>Timperley<br>1st Friday of each<br>month 7.30 p.m.                               |
| Aylesbury Astronomical Society               | 9 Elm Close, Butler's<br>Cross, Aylesbury<br>(N. Neale)                     | £1                                                              | As arranged                                                                                            |
| Barrow-in-Furness Astronomical Society       | The Villas<br>Newton-in-Furness,<br>Lancs                                   | —                                                               | —                                                                                                      |
| Birmingham Astronomical Society              | 14 Plants Brook Road,<br>Walmley, Sutton<br>Coldfield<br>(A. R. J. Foulger) | £1 (\$25p)                                                      | Birmingham and<br>Midland Institute<br>Monthly                                                         |
| Border Astronomical Society                  | 14 Shap Grove,<br>Carlisle, Cumbria<br>(David Pettitt)                      | —                                                               | Morton Community<br>Centre, Wigton Road,<br>Carlisle<br>Monthly by<br>arrangement                      |
| Bridgwater Astronomical Society              | The Bridgwater College,<br>Bridgwater, Somerset<br>(W. L. Buckland)         | 75p<br>(\$30p)                                                  | Room 4,<br>Blake St. Centre,<br>Bridgwater College,<br>3rd Wednesday in each<br>month.                 |
| Brighton Astronomical Society                | Flat 2, 23 Albany Villas,<br>Hove, Sussex, BN3 2RS<br>(Mrs B. C. Smith)     | £1 (\$50p)                                                      | Preston Tennis Club,<br>Preston Drive,<br>Brighton.                                                    |
| Bristol Astronomical Society                 | 34 Butterfield Close,<br>Bristol BS10 5AZ<br>(G. H. Woodman)                | £2.50<br>(\$52+p)                                               | Weekly. Tuesdays.<br>Royal Fort (Rm G44)<br>Bristol University<br>last Friday each<br>month, Sept.-May |

# 1976 YEARBOOK OF ASTRONOMY

| <i>Name</i>                                                  | <i>Secretarial Address</i>                                                               | <i>Yearly<br/>Subscription<br/>£=members<br/>under 18, or<br/>'juniors'</i> | <i>Meeting Time and Place</i>                                                                                     |
|--------------------------------------------------------------|------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| Caithness and Dounreay<br>Astronomical Society               | Room 31, Ormlie Lodge,<br>Thurso, Scotland<br>(Miss M. J. A. Clark)                      | £1                                                                          | Fortnightly                                                                                                       |
| Camberley (Surrey)<br>Astronomical Society                   | 75 Christchurch Drive,<br>Blackwater, Surrey<br>(Ron Toft)                               | £1 (\$50p)                                                                  | Adult Education Centre,<br>Watchetts Drive,<br>Camberley, Surrey<br>2nd Wednesday each<br>month, 7.30 p.m.        |
| Cambridge Astronomical<br>Society                            | 5 Haggis Gap,<br>Fulbourn<br>(S. R. Whistler)                                            | £1.05<br>(\$37½p)                                                           | 7 Brooklands Avenue,<br>Cambridge<br>2nd Mon. each month<br>Oct.-July                                             |
| Chelmsford and District<br>Astronomical Society              | 70 Maldon Road,<br>Burnham-on-Crouch<br>(Miss C. C. Puddick)                             | £1 (\$50p)                                                                  | Sandon House School,<br>Chelmsford<br>Last Mon. in month<br>7.30 p.m.                                             |
| Chester Astronomical<br>Society                              | 37 Alwyn Gardens,<br>Upton, Chester<br>(A. Kemp)                                         | £2 (\$50p)                                                                  | St Andrews House,<br>Newgate St., Chester<br>Monthly                                                              |
| Chester Society of<br>Natural Science,<br>Literature and Art | Wood Farm,<br>Tattenhall Lanes,<br>Tattenhall, nr Chester<br>(Geoffrey Lake)             | —                                                                           | Grosvenor Museum,<br>Chester<br>Fortnightly                                                                       |
| Chesterfield Astronomical<br>Society                         | Hilltop Cottage,<br>Gallery Lane,<br>Holymoorside,<br>Chesterfield<br>(Mrs R. C. Naylor) | £1 (\$50p)                                                                  | Barnett Observatory,<br>Newbold<br>Each Friday                                                                    |
| Clackmannanshire<br>Astronomical<br>Society                  | 9 Deer Park,<br>Sauchie, Alloa<br>(J. Cluckie)                                           | £1                                                                          | St Mary's School,<br>Alloa<br>Monthly, 3rd Friday<br>Sept.-May                                                    |
| Clacton & District<br>Astronomical<br>Association            | 105 London Road,<br>Clacton-on-Sea, Essex<br>(C. L. Haskell)                             | —                                                                           | —                                                                                                                 |
| Cleethorpes & District<br>Astronomical Society               | 236 Humberston Avenue,<br>Humberston, Grimsby,<br>South Humberside<br>(P. H. Rea)        | £2 (\$50p)                                                                  | Beacon Hill Observatory,<br>Cleethorpes<br>1st Wednesday<br>each month                                            |
| Coventry & Warwicks<br>Astronomical Society                  | 238 Sovereign Road,<br>Earlsdon, Coventry<br>Warwicks                                    | —                                                                           | Coventry Technical<br>College<br>Fortnightly                                                                      |
| Crawley Astronomical<br>Society                              | 27 York Road, Crawley<br>Sussex<br>(A. Drummond)                                         | £1(\$50p)                                                                   | Crawley College of<br>Further Education<br>Monthly Oct-June                                                       |
| Crayford Manor House<br>Astronomical Society                 | Manor House Centre,<br>Crayford, Kent<br>(R. H. Chambers)                                | None                                                                        | Manor House Centre,<br>Crayford<br>Monthly during term-<br>time                                                   |
| Croydon Astronomical<br>Society                              | 12 Elstan Way,<br>Shirley, Croydon<br>(K.E. Stanbridge)                                  | —<br>5p entrance<br>fee to<br>meetings                                      | The Old Whitgiftian<br>Sports Club,<br>Lime Meadow Ave.,<br>Sanderstead, Surrey<br>Alternate Fridays<br>7.45 p.m. |
| Derby & District<br>Astronomical Society                     | The Guildhall,<br>Market Place, Derby<br>(F. Shaw)                                       | £1.50<br>(\$50p)                                                            | 1st Friday each month,<br>at The Hollies                                                                          |
| Dundee Astronomical<br>Society                               | 80 Torridon Road,<br>Broughty Ferry,<br>Dundee<br>(K. Kennedy)                           | 50p (\$25p)                                                                 | Mills Observatory,<br>Dundee<br>Fortnightly in the<br>winter                                                      |
| Eastbourne Astronomical<br>Society                           | Flat 3, 17 Hartfield Road,<br>Eastbourne<br>(T. Allchin)                                 | £1.50<br>(\$75p)                                                            | As arranged<br>Monthly                                                                                            |

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|---------------------------------------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| East Lancashire Astronomical Society        | 16 Worston Lane,<br>Great Harwood,<br>Blackburn, BB6 7TH<br>(D. Chadwick)           | £1-50<br>Juniors, etc.<br>75p                                   | As arranged<br>Monthly                                                                             |
| Astronomical Society of Edinburgh           | 126 W. Saville Terrace,<br>Edinburgh 9,<br>Scotland<br>(N. G. Matthew)              | £1                                                              | Calton Hill Observatory.<br>Edinburgh<br>Monthly                                                   |
| Ewell Astronomical Society                  | 11 Elmwood Drive,<br>Ewell, Surrey<br>(L. J. Bentley)                               | £1 (\$50p)                                                      | Ewell County Technical<br>College, Reigate Road,<br>Ewell, Surrey<br>1st Friday of each<br>month   |
| Farnham Astronomical Society                | 10 Willow Way,<br>Hale, Farnham, Surrey<br>(John Fannon)                            | £1                                                              | Adult Education Centre,<br>32 South Street,<br>Farnham<br>2nd Monday each<br>month, 7.45 p.m.      |
| Fellowship of Junior Astronomers, Edinburgh | 58 Ogilvie Terrace,<br>Edinburgh 11,<br>Scotland<br>(Miss Edith McLean)             | 50p                                                             | Calton Hill Observatory,<br>Edinburgh<br>3rd Fri. each month,<br>Sept.-June                        |
| Fylde Astronomical Society                  | 28 Belvedere Rd,<br>Thornton, Lancs<br>(—)                                          | £1 (\$50p)                                                      | Stanley Hall,<br>Rossendale Ave. South<br>1st Wed. each month                                      |
| Astronomical Society of Glasgow             | 8 Kirkoswald Road,<br>Newlands,<br>Glasgow<br>(H. Palmer)                           | £1 (\$50p)                                                      | University of<br>Strathclyde, George<br>Street, Glasgow<br>3rd Thursday each<br>month, Sept.-April |
| Great Yarmouth Astronomical Society         | 10 Tyrrells Road,<br>Great Yarmouth,<br>Norfolk<br>(M. Poxon)                       | £1 (\$75p)                                                      | Public Library<br>Alternate Fridays                                                                |
| Guildford Astronomical Society              | 12 Durham Close,<br>Guildford<br>(Mrs. D. E. Clapson)                               | £1                                                              | Corona Restaurant,<br>High Street, Guildford<br>1st Tue. each month<br>7.45 p.m.                   |
| Gwynedd Astronomical Society                | 2 Rhos Groes, Sling<br>Bangor, Gwynedd<br>(E. Parry)                                | £2 (\$£1<br>& students)                                         | Physics Lecture Room,<br>Bangor University<br>1st Thursday each<br>month, 7.30 p.m.                |
| Astronomical Society of Haringey            | 58 Stirling Road,<br>Wood Green,<br>London, N22<br>(W. T. Baker)                    | 50p (\$20p)                                                     | 673 Lordship Lane,<br>Wood Green,<br>London, N22<br>3rd Thurs. each month<br>7.30 p.m.             |
| Herschel Society                            | 35 Kendal Drive,<br>Slough<br>(C. Wise)                                             | —                                                               | (To be announced)                                                                                  |
| Isle of Wight Astronomical Society          | 1 Hilltop Cottages, High<br>Street, Freshwater,<br>Isle of Wight<br>(J. W. Feakins) | £1 (\$50p)                                                      | Unitarian Church Hall,<br>Newport, Isle of<br>Wight<br>Monthly                                     |
| Leeds Astronomical Society                  | Maths. Dept.,<br>The University,<br>Leeds 2<br>(B. L. Meek)                         | 50p (\$25p)                                                     | Leeds University<br>Six annually                                                                   |
| Leicester Astronomical Society              | 26 Falmouth Rd.,<br>Evington, Leicester<br>(Mrs L. Withey)                          | £1.05 (37p)                                                     | Leicester Museum and<br>Art Gallery<br>Monthly                                                     |
| Lincoln Astronomical Society                | 344 Brant Road,<br>Lincoln<br>(P. Hammerton)                                        | £1 (\$25p)                                                      | Lincoln YMCA Hall<br>1st Tue. each month                                                           |

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|-------------------------------------------------|----------------------------------------------------------------------------------------|------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| Liverpool Astronomical Society                  | Simms Cross School Hse.,<br>Milton Road, Widnes<br>(D. Bradburne)                      | £1·50 (\$75p)                                                                | City Museum,<br>Liverpool<br>Monthly                                                                                                              |
| Livingston Astronomical Society                 | 50 Dawson Avenue,<br>Howden, Livingston,<br>West Lothian                               | £2 (\$£1)                                                                    | Almond Room, Howden<br>House, Howden<br>Sundays, 7.30 p.m.                                                                                        |
| Loughton Astronomical Society                   | 6 Baldock Road,<br>Theydon Bois,<br>Epping, Essex<br>(S. Smith)                        | £1·50 (\$£1)                                                                 | Loughton Hall,<br>Rectory Lane,<br>Loughton, Essex<br>Thursdays, 8 p.m.                                                                           |
| Luton Astronomical Society                      | 20 Bloomfield Avenue,<br>Luton<br>(S. J. Anderson)                                     | £1                                                                           | Last Friday each month                                                                                                                            |
| Lytham St. Annes<br>Astronomical<br>Association | 141 Blackpool Road,<br>Ansdell,<br>Lytham St. Annes,<br>Lancs.<br>(K. J. Porter)       | 50p (\$25p)<br>+ 5p per<br>meeting                                           | College of Further<br>Education,<br>Clifton Drive S.,<br>Lytham St. Annes<br>2nd Wed. monthly<br>Oct.-June                                        |
| Maidenhead Astronomy<br>Group                   | 129 Fane Way,<br>Maidenhead,<br>Berkshire<br>(S. A. H. Roper)                          | 50p (\$12½p)                                                                 | Maidenhead Grammar<br>School<br>Once every 3 weeks                                                                                                |
| Manchester Astronomical<br>Society              | Cragside, Cliff Avenue,<br>Summerseat, Bury<br>(Alan Whittaker)                        | £1 (\$50p)                                                                   | Godlee Observatory,<br>Manchester 1<br>Weekly                                                                                                     |
| Mansfield and District<br>Astronomical Society  | 14 Bonnington Crescent,<br>Sherwood Estate,<br>Nottingham<br>(G. W. Shepherd)          | 50p (\$25p)                                                                  | Monks Precision<br>Engineering Co.,<br>Mansfield Rd.,<br>Sutton-in-Ashfield<br>Last Monday of each<br>calendar month                              |
| Mid-Sussex<br>Astronomical Society              | 19 Blackthorns,<br>Lindfield,<br>Sussex<br>(G. A. N. Molloy)                           | £2 (\$£1)                                                                    | Haywards Heath<br>Grammar School<br>Wednesdays<br>7.30 p.m.                                                                                       |
| Milton Keynes<br>Astronomical Society           | 26 Betty's Close,<br>Newton Longville,<br>Milton Keynes,<br>MK17 0AN<br>(Paul D. Keen) | 10p (\$5p)<br>per<br>meeting<br>£1                                           | Alternate Tuesdays                                                                                                                                |
| Newcastle-on-Tyne<br>Astronomical Society       | 30 Kew Gardens,<br>Whitley Bay,<br>Northumberland<br>(G. E. Manville)                  | £1                                                                           | Botany Lecture Theatre<br>Newcastle University<br>Monthly, Sept.-April                                                                            |
| Newtonian Observatory<br>Astronomical Society   | 62 Northcott Road,<br>Worthing, Sussex<br>(Miss P. E. Randle)                          | £1·20                                                                        | Adult Education Centre<br>Union Place,<br>Worthing<br>1st Wed. each month<br>except Aug. 7.30 p.m.                                                |
| North Devon<br>Astronomical Society             | Ararat,<br>18 The Shields,<br>Ilfracombe, North Devon<br>(R. W. Rose)                  | Details to be announced later                                                |                                                                                                                                                   |
| North Dorset<br>Astronomical Society            | The Pharmacy,<br>Stalbridge, Dorset<br>(J. E. M. Coward)                               | —                                                                            | Charterhay, Stourton,<br>Caundle, Dorset<br>2nd Wed. each month                                                                                   |
| North Wilts/South<br>Glos Astronomical<br>Group | 'Kelston', Gloucester<br>Road, Malmesbury, Wilts<br>(Simon D. Barnes)                  | —                                                                            | To be announced                                                                                                                                   |
| Norwich Astronomical<br>Society                 | The Manse,<br>Back Lane,<br>Wymondham, Norwich<br>Rev. Cyril D. Blount)                | £1 (\$50p)                                                                   | Norwich Observatory,<br>Colney Lane,<br>Cringeford, Norwich<br>Every Tues. and Sat.<br>Public meetings 3rd<br>Sat. at Spinney<br>Community Centre |

# ASTRONOMICAL SOCIETIES

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|-------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Nottingham<br>Astronomical<br>Society           | 18 Naseby Close,<br>Heathfield, Nottingham<br>(C. Swift)                                             | £1·25p                                                                       | Monthly                                                                                  |
| Orion Astronomical<br>Society                   | 11 Hunter Place,<br>Louth, Lincolnshire<br>(T. P. Byatt)                                             |                                                                              | Details to be announced                                                                  |
| Orwell Astronomical<br>Society (Ipswich)        | 33 Crofton Road,<br>Ipswich, Suffolk<br>(M. Hadden)                                                  | £1·05 (\$5p)                                                                 | Orwell Park School<br>Nacton, Ipswich<br>Weekly                                          |
| Oxshott Astronomical<br>Group                   | Norman Cottage,<br>Pond Piece, Sheath<br>Lane, Oxshott, Surrey<br>(E. H. Noon)                       | 50p                                                                          | Oxshott Village Centre<br>1st Wed. each month<br>Sept.-May                               |
| Paisley Astronomical<br>Society                 | 14 Cheviot Avenue,<br>Barrhead, Glasgow<br>(Mrs J. Holms)                                            | £1 (\$50p)                                                                   | Coats Observatory,<br>49 Oakshaw Street,<br>Paisley<br>Monthly                           |
| Peterborough<br>Astronomical<br>Society         | 24 Cissbury Ring<br>Werrington,<br>Peterborough<br>(E. Pitchford)                                    | £1·25<br>(\$25p)                                                             | Peterborough Technical<br>College<br>2nd Tues., 3rd Thur.<br>each month                  |
| Phoenix<br>Astronomical Society                 | 38 Myers Avenue,<br>Bolton, Bradford 2,<br>Yorks.<br>(B. Jones)                                      | —                                                                            | Phoenix Park Sports<br>Club, off Dick Lane,<br>Thornbury,<br>Bradford 3.                 |
| Plymouth Astronomical<br>Society                | 1 Valletort Cotts,<br>Millbridge, Plymouth<br>(G. S. Pearce)                                         |                                                                              | Plymouth College of<br>Technology, Tavistock<br>Road, Plymouth<br>Monthly                |
| Portsmouth Astronomical<br>Group                | 52 Denbigh Drive,<br>Fareham, Hampshire<br>(S. W. Hackman)                                           | £3                                                                           | The Group Observatory                                                                    |
| Portsmouth Astronomical<br>Society              | 91 Sutherland Road,<br>Southsea<br>(P. R. Seiden)                                                    | £1·50                                                                        | Monday<br>Fortnightly                                                                    |
| Preston and District<br>Astronomical Society    | 35 Bispham Road,<br>Carleton,<br>Poulton-le-Fylde, Lancs<br>(C. Lynch)                               | £1 (\$25p)                                                                   | Chamber of Commerce,<br>49a Fishergate,<br>Preston<br>3rd Mon. each month<br>Sept.-May   |
| Rayleigh Centre Amateur<br>Astronomical Society | 136 The Chase,<br>Rayleigh, Essex<br>(Bernard R. Soley)                                              | £1·50 (80p)                                                                  | Fitzwimarc School,<br>Hockley Road,<br>Rayleigh<br>Every Wed., 8 p.m.                    |
| Reading Astronomical<br>Society                 | 30 Amherst Road,<br>Reading<br>(J. Wrigley)                                                          | 75p (\$25p)                                                                  | Anderson Baptist<br>Church Hall, Reading<br>Monthly                                      |
| Salford Astronomical<br>Society                 | 44 Pevensey Road,<br>Salford 6<br>(A. Taylor)                                                        | £1 (\$50p)                                                                   | The Observatory,<br>3rd Wed. each month                                                  |
| Salisbury Plain<br>Astronomical Society         | St George's Cottage,<br>Orcheston,<br>Salisbury, Wilts.<br>(R. J. D. Nias)                           | 50p (\$25p)                                                                  | St George's Rectory<br>Orcheston<br>Quarterly                                            |
| Slough Astronomical<br>Society                  | The Elms, Odds Farm,<br>Green Common Lane,<br>Wooburn Common,<br>High Wycombe, Bucks<br>(E. Shilton) | £1                                                                           | Monthly                                                                                  |
| Solent Amateur<br>Astronomers                   | 14 Orchard Avenue,<br>Bishopstoke, Eastleigh,<br>Hants.<br>(R. W. Arbour)                            | £1·50<br>(\$75p)<br>certain<br>students<br>50p                               | Room 33, Library Block,<br>Southampton<br>University. 3rd Thur.<br>each month. 7.30 p.m. |

# 1976 YEARBOOK OF ASTRONOMY

| <i>Name</i>                                             | <i>Secretarial Address</i>                                                                         | <i>Yearly<br/>Subscription<br/>£=members<br/>under 18, or<br/>'juniors'</i> | <i>Meeting Time and Place</i>                                                                                                          |
|---------------------------------------------------------|----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| South Downs<br>Astronomical Society                     | 32 Birdham Close,<br>Stroud Green,<br>Bognor Regis<br>(Mrs Buss)                                   | £2 (££1)                                                                    | Last Friday in each<br>month                                                                                                           |
| South East Essex<br>Astronomical Society                | 42 First Avenue,<br>Westcliff-on-Sea,<br>Essex SS0 8HR<br>(P. A. Laycock)                          | £1 (\$50p)                                                                  | Lecture Theatre, Central<br>Library, Victoria<br>Avenue, Southend-<br>on-Sea<br>Generally 1st Thurs.<br>in month, Sept.-May            |
| Southampton<br>Astronomical Society                     | 4 Heathfield,<br>Dibden Purlieu,<br>Southampton<br>(J. G. Thompson)                                | £2 (££1)                                                                    | 2nd Thur. each month<br>Unigate Conference<br>Room, Southampton<br>4th Thursday each<br>month<br>Room 33, University<br>of Southampton |
| Southport Astronomical<br>Society                       | 37 Park Avenue,<br>Southport<br>PR9 9EF<br>(Malcolm Thomas)                                        | 75p                                                                         | As arranged<br>Monthly                                                                                                                 |
| South-East Kent<br>Astronomical Society                 | 30 Reach Close,<br>St Margaret's Bay,<br>nr Dover<br>(P. Andrew)                                   | £1 (\$70p)                                                                  | Monthly                                                                                                                                |
| South Shields<br>Astronomical Society                   | Marine and Technical<br>College, St George's<br>Ave., South Shields,<br>Co. Durham<br>(H. Haysham) | £1 (37½p)                                                                   | Marine and Technical<br>College<br>Each Thursday,<br>7.30 p.m.                                                                         |
| South West Herts<br>Astronomical Society                | 32 Riverford Close,<br>Harpenden,<br>Herts.<br>(G. J. B. Phillips)                                 | £1·50 (\$75p)                                                               | Royal Masonic School<br>for Girls,<br>Rickmansworth<br>Last Fri. each month<br>Sept.-May                                               |
| Stoke-on-Trent<br>Astronomical Society                  | Sundale, Dunnocksfold<br>Road, Alsager, Stoke<br>(M. Pace)                                         | 75p                                                                         | Cartwright House,<br>Broad Street, Hanley<br>Monthly                                                                                   |
| Swansea Astronomical<br>Society                         | 30 Cwrt-y-Clafdy,<br>Skewen, nr Neath,<br>Glamorganshire<br>(C. Morris)                            | £1·50 (\$25p)<br>Students 50p                                               | As arranged                                                                                                                            |
| Thanet Amateur<br>Astronomical Society                  | 85 Crescent Road,<br>Ramsgate<br>(P. F. Jordan)                                                    | 25p                                                                         | Hilderstone House,<br>Broadstairs, Kent<br>Monthly                                                                                     |
| Torbay Astronomical<br>Society                          | 4 Heath Rise,<br>Brixham, Devon<br>(Miss A. Longman)                                               | 75p (\$25p)                                                                 | Quay Tor Hotel,<br>Scarborough Road,<br>Torquay. Monthly                                                                               |
| Waltham Forest and<br>District Junior<br>Astronomy Club | 24 Fulbourne Road,<br>Walthamstow,<br>London E17<br>(B. Crawford)                                  | 50p                                                                         | 24 Fulbourne Road,<br>Walthamstow,<br>London E17<br>Fortnightly (Mondays)                                                              |
| Warrington Astronomical<br>Society                      | 2 Dale Avenue,<br>Appleton,<br>Warrington<br>(B. P. Rees)                                          | £1                                                                          | Central Library,<br>Museum Street,<br>Warrington, Lancs<br>Monthly, Sept.-May                                                          |
| Warwickshire<br>Astronomical Society                    | 20 Humber Road,<br>Coventry,<br>Warwickshire<br>(R. D. Wood)                                       | £4                                                                          | 20 Humber Road,<br>Coventry<br>Each Tuesday                                                                                            |
| Webb Society                                            | 7 Elvendon Road,<br>Palmer's Green,<br>London, N.13<br>(E. Moore)                                  | £1 (\$75p)                                                                  | As arranged                                                                                                                            |

# ASTRONOMICAL SOCIETIES

| <i>Name</i>                            | <i>Secretarial Address</i>                                                               | <i>Yearly<br/>Subscription<br/>£=members<br/>under 18, or<br/>'juniors'</i>                               | <i>Meeting Time and Place</i>                                                                                         |
|----------------------------------------|------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| Wessex Astronomical Group              | St Catherine's Court,<br>D4,<br>35 Christchurch Road,<br>Bournemouth<br>(Mrs H. Bagainy) | —                                                                                                         | Ashley Cross Girls<br>School,<br>Lower Parkstone,<br>Poole, Dorset<br>1st Tues. each month<br>(except Aug.) 7.30 p.m. |
| West of London<br>Astronomical Society | 5 Blakesley Avenue,<br>Ealing, W5 2DN<br>(P. Macdonald)                                  | 40p                                                                                                       | Monthly, alternately at<br>Ruislip and North<br>Harrow<br>2nd Monday of the<br>month (except August)                  |
| West Yorkshire<br>Astronomical Society | 76 Katrina Grove,<br>Purston, Pontefract,<br>Yorks. WF7 5LW<br>(J. A. Roberts)           | 50p (\$25p)<br>entrance fee<br>75p (\$25p)                                                                | The Barn, 4 The Butts,<br>Back Northgate,<br>Pontefract<br>Every Tues. 7 p.m.                                         |
| Wolverhampton<br>Astronomical Society  | Garwick, 8 Holme Mill,<br>Fordhouses,<br>Wolverhampton<br>(M. Astley)                    | Under 18-<br>40p<br>Over 18-<br>£1.50<br>Joint Sub.<br>Man &<br>Wife- £2.50<br>Retired<br>persons-<br>50p | Polytechnic,<br>Wulfruna Street,<br>Wolverhampton<br>Alternate Mon.,<br>Sept.-April                                   |
| Wyvern Astronomical<br>Society         | 2 Howcroft,<br>Churchdown, Gloucester<br>(A. F. Edwards)                                 | 75p (\$25p)                                                                                               | Clubhouse, Churcham<br>Last Friday of each<br>month except Aug.                                                       |
| York Astronomical<br>Society           | 1 Low Catton Road,<br>Stamford Bridge, York.<br>(Mrs J. Acton)                           | £2 (\$£1)                                                                                                 | York Railway Institute.<br>Fortnightly Fridays.                                                                       |
| Zenith Astronomical<br>Society         | 10 Meadow Close,<br>Reedby,<br>nr Burnley<br>(A. Harvey)                                 | —                                                                                                         | 54 Cromwell Street,<br>Burnley<br>1st Wednesday in<br>each month                                                      |

It is possible that this list of local societies may not be quite complete. If any have been omitted, or any details need to be updated, the secretaries concerned are invited to write to the Editor (c/o Messrs Sidgwick & Jackson (Publishers), Ltd, 1 Tavistock Chambers, Bloomsbury Way, London WC1), so that the relevant notes may be included in the 1977 *Yearbook*.

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